N74 32397

THE SPACE APPLICATIONS PROGRAM 1974

NATIONAL AERONAUTICS & SPACE ADMINISTRATION

OFFICE OF APPLICATIONS

WASHINGTON, D.C.

Review of

THE SPACE APPLICATIONS PROGRAM 1974

by

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
OFFICE OF APPLICATIONS
WASHINGTON, DC 20546

MAY 1974

CONTENT

CHAPTER I. INTRODUCTION

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER I. INTRODUCTION

1. PURPOSE

The purpose of this review is to provide the participants in the National Aeronautics and Space Administration/National Academy of Engineers' Summer Study in Applications a concise overview of the NASA Applications Program as it stands in 1974. The review covers the accomplishments of the various discipline-oriented programs that make up the total Applications Program, discusses the program plan for the 1975 to 1980 period, and examines the anticipated spaceflight capabilities of the 1980's.

2. OBJECTIVES OF THE SUMMER STUDY

NASA has requested the National Academy of Engineers to conduct through its Space Applications Board a comprehensive study of the future space applications program encompassing the following:

a. The Applications Program in general, with particular emphasis on practical approaches, including assessment of the socio-economic benefits.

b. How the broad comprehensive program envisioned above influences, or is influenced by, the Shuttle system, the principal space transport system of the 1980's.

The 1967 and 1968 National Academy of Sciences' study of the "Useful Applications of Earth-Oriented Satellites" has been a landmark in the development of the NASA Applications Program. But there is now a need to update that study, a need based on new and demonstrated capabilities, and, in particular, to factor in the capabilities of the space transportation system and the Spacelab which will be operational in the 1980's.

3. STRUCTURE OF THE STUDY

To meet the objectives, the study has been structured around nine user-oriented panels, as identified in Table I-1. Three groups, Economic Benefits, Domestic Institutional Factors, and Space Transportation System/Spacelab, will interact with all the panels (and each other) to examine the economic, institutional, and transportation aspects of the programs defined by the various panels.

TABLE 1. PANELS AND RELEVANT CHAPTERS

Panels and Groups	Relevant Chapters[a]
1. Weather and Climate	IV, III. A
2. Communications	V
3. Land Use Planning	IV, III. B
4. Agricultural Resources	III. B
5. Inland Water Resources	IV, V, III. B
6. Extractive Resources	IV, III. B
7. Environmental Quality	IV, V, III. C
8. Marine and Maritime Uses	IV, V, III. B
9. Materials Processing	VI
10. Institutional Arrangements	All Chapters
11. Costs and Benefits	All Chapters
12. Space Transportation	All Chapters

a. Chapters I, II, VIII, IX, and X may be of interest to all participants.

To support the panels and groups in their activities, a team of NASA specialists and technologists will be available to discuss the characteristics of the present Applications Program and the capabilities, in terms of the Spacelab, Space Shuttle, spacecraft, instruments, etc., planned for spaceflight in the future.

4. ORGANIZATION OF THIS REVIEW

This review is organized by chapters, each covering a programmatic element of the Applications Program; i.e., the Earth Observations Program, the Space Processing Program, and so on. The internal structure of each of

the chapters follows a common format in which the history of the program element, its goals and objectives, the program itself, schedules, funding, cost/benefit studies, and institutional arrangements unique to that program are discussed.

To enable the participants in the study to identify program or discipline activities of most interest to them, a guide has been drawn up (Table 1) in which the chapters relevant to each of the study panels is identified.

In the preparation of this review, we have attempted to keep the main body of it in a manageable size. Detailed information on the flight missions and other details have been put into a second volume, the Appendices. Separate reports have been prepared covering the specifics of the Space Transportation System (the Shuttle and the Tug), the Spacelab, and a major support function, the tracking and data acquisition activities of NASA. Copies of these documents will be distributed to all participants. A library of all key references will be available at the study.

CHAPTER II. SUMMARY AND OVERVIEW

TABLE OF CONTENTS

CHAPTER II. SUMMARY AND OVERVIEW

1. NASA OBJECTIVES IN APPLICATIONS

In the National Aeronautics and Space Act of 1958, the legislation creating NASA, the Agency was charged with the responsibility of developing aeronautics and spaceflight capabilities "for the benefit of all mankind." For applications, this responsibility has evolved into the following objectives:

a. To develop and test procedures, instruments, spacecraft, and interpretative techniques in the various disciplines in Applications.

b. To accomplish long-range studies of the potential benefits to be gained from, and the problems involved in, the utilization of space capabilities.

c. To conduct a comprehensive and meaningful space applications program to help maintain U.S. scientific, technological, and economic leadership.

The primary thrust of the NASA program has been to conduct the research and development activities necessary to demonstrate the applicability of a system or technique to the planning and management responsibilities of another Federal agency or a segment of the economic activities of the Nation. Thus NASA conducted the research and development and demonstration leading to the first meteorological satellite system, Tiros. The Department of Commerce/National Oceanic and Atmospheric Administration ultimately underwrote this operational meteorological satellite program as part of its responsibilities for the national weather services. This arrangement, whereby NASA funds and conducts the R&D programs and the user agency or organization conducts the operational program, is well established in both the meteorology and communications programs.

The Communications Satellite Act of 1962 called for the establishment of a private corporation to develop a commercial communications satellite system in cooperation with other countries. Under the Act of 1962, NASA has certain responsibilities relating to the establishment of a global communications satellite system, including:

a. Advising the FCC and the Department of State on technical matters.

b. Cooperation and consultation with the private corporation.

c. Furnishing launch services.

Other Applications Programs are not so well established operationally.

2. SCOPE OF THE APPLICATIONS PROGRAM

The NASA Applications Program encompasses a very wide range of activities involving many of the science, geophysics, and engineering disciplines which form the basis of many R&D programs. The present programmatic structure is:

- Earth Observations
- Earth and Ocean Physics Applications
- Communications and Navigation
- Space Processing
- Future Applications
- Data Management
- User Affairs

Each of these programs involves NASA internal and/or NASA-funded basic scientific investigations; studies of the objectives of the programs, observing requirements, user needs, system analyses; balloon, aircraft, and sounding rocket support programs; instrument and other hardware developments; spacecraft design, development, manufacture, and in-flight operations; and in some cases major efforts in data management — the processing, archiving, and dissemination of the data acquired in the programs.

The Earth Observations program is subdivided, for organizational convenience, into subprograms in weather and climate, earth resources survey, and environmental quality. The observational techniques required by each of these subprograms have many aspects in common and, indeed, frequently use the same instruments.

- The weather and climate subprogram is directed toward providing operational support and investigations in weather prediction research (particularly global modeling), atmospheric pollution, climate and weather modification, weather danger and disaster warning, and atmospheric processes and interactions.

- The earth resources survey subprogram includes wide-ranging activities in land-use mapping, hydrology, geology, agriculture (such as crop identification, vigor, stress, and yield), forestry, water resources (such as flood plain mapping), and marine resources.

- The environmental quality subprogram is focused on the detection and monitoring of atmospheric, land, and water pollution on local, regional, and global scales in support of the environmental agencies.

The Earth and Ocean Physics Applications program is subdivided into two subprograms, ocean dynamics and earth dynamics.

- The ocean-dynamics subprogram is addressed to the monitoring and forecasting of ocean-surface conditions on a global, near-real-time basis to provide for more efficient use of the oceans.

- The earth-dynamics subprogram is addressed to observing the solid earth's dynamical motions (such as plate motion) in order to make contributions to the knowledge of earthquake mechanisms and the development of earthquake prediction models.

The Communications and Navigation program went through a phasedown as related to early commercial utilization, as announced by NASA in January 1973, and is now being redirected. During the course of this phasing down, it has become apparent that a complete termination of the NASA effort was not acceptable to several executive and legislative agencies that have traditionally relied on NASA to provide technical consultation and support for their needs in satellite communications. NASA has a statutory obligation to provide such services. Moreover, some Government agencies have requested NASA support for their special mission needs on a reimbursable basis. Based on these factors, NASA objectives in satellite communications have been refocused toward meeting longer-term national needs. These needs, as expressed by legislative and executive agencies, including NASA, require that the unique, in-Government technical and management capabilities in satellite communications that we have developed over the past decade be maintained and made available as agencies request.

The NASA satellite communications program has been organized principally around NASA needs in spacecraft technology and telecommunications, frequency sharing and interference studies to determine NASA frequency and orbit requirements, and methods and techniques for expanding the utilization of the crowded frequency spectrum by exploring advanced concepts such as data compression techniques and the uses of higher frequency bands. In support of these needs is a modest research and development effort at the "cutting edge" of communications technology, focusing on advanced concepts and techniques. No new flight projects are currently envisioned.

The Space Processing program which was formalized in NASA just over one year ago has as its ultimate goal the development of commercially-oriented, private utilization of spaceflight capabilities in fields related to materials science and technology.

The Future Applications program in NASA is currently directed to energy and technology applications.

- The Energy Application subprogram includes studies of space- and earth-based solar power generating systems, the technology of microwave power transmission systems, the clean fuel systems problems, particularly in hydrogen as a nonpolluting material for energy storage, transmission and utilization, and studies of energy and environment conservation systems. In the latter, the major effort is in a Modular Intergrated Utility System, a Department of Housing and Urban Development sponsored program in NASA.

- The Technology Applications subprogram has as its objective the involvement of NASA's aerospace technology, technologists and managerial know-how in the development of ground-based systems that can contribute to Federal, state, and local efforts to improve the quality of life in a more secure environment.

There are two additional major activities in the NASA Applications Program which, although not strictly programmatic (they support all of the Applications programs) warrant brief discussion.

- The Data Management Systems program is new in the FY-75 program. The objective of this program is the study, design, development and demonstration of data acquisition and transmission systems which will have the necessary capability to process, store, and distribute information in the volumes forecast for many applications. It is focused today principally on the earth resources and weather and climate applications.

• The User Affairs program has as its objectives the identification of user needs and requirements and the assessment of their impact on the Applications Program; the obtaining of the active support and participation of the users in the programs; and the provision of an effective systems capability to assess the economic and social values flowing from the Applications Program.

3. THE 1967-1968 SUMMER STUDY

During the summers of 1967 and 1968, the National Academy of Sciences (NAS), at the request of the NASA Administrator, organized and carried out a comprehensive study of the useful applications of earth-oriented satellites. Priority was to be given to both the technological considerations and the assessment of the relative benefits that might be achieved. In his letter of transmittal, the Director of the Summer Study stated:

> Two comprehensive conclusions emerged from the Summer Study on Space Applications. The first is that the benefits to be obtained from practical space applications appear to be large — larger, in fact, than most of the participants in the Study anticipated and much larger than the cost of achieving those benefits. The second comprehensive conclusion is that an extensive, coherent, and selective program will be required to achieve these benefits.

The Study Director further noted that the recommendations implied "that the Federal budget for the development of practical Applications of unmanned satellites be rapidly increased to a level two to three times greater than the current level of budgetary support."

The 1967-1968 Study was organized around a group of technical panels with broad responsibilities for scrutinizing applications in meteorology, hydrology, oceanography, forestry, agriculture, geography, geology, sensors and data systems, point-to-point communications, broadcasting, navigation and traffic control, cartography and geodesy. An economic analysis panel was formed and an ad hoc group explored (and reported on) the multinational implications of the applications systems that had been postulated. The thrust of that summer study was largely technical: what are the needs, how might satellites satisfy these needs, what capabilities are needed, what feasible systems are possible. These objectives were quite different from those of the currently planned study.

The NASA response to the many (18 in all) recommendations was, where it was able to respond, favorable. Programmatic funding did rise to double its previous levels in the following years (see Chapter X, Figs. 1 and 2). The bulk of the increases occurred in the earth resources survey program with the enhancement of the aircraft program (as recommended) and the development and launch of the Earth Resources Technology Satellite whose potential was a major factor contributing to the optimism of the study participants. Another significant step by NASA, partly in response to the study report, was the creation of a separate Office of Applications in the NASA Headquarters organization on a level with the Offices of Space Sciences, Manned Space Flight and others. This reorganization substantially strengthened the role of the Applications Program within the Agency and the visibility to Congress, the public, and other Federal institutions.

The 1967-1968 NAS Summer Study was a major landmark in the NASA Applications Program, particularly with respect to the earth resources survey program, but also in communications and navigation with the development of its Applications Technology Satellite F broadcast and point-to-point communications experiments and by the growth in the earth and ocean physics applications programs in geodesy (see Chapters V and IV, respectively).

The programmatic institutional interfaces and contacts have grown substantially in years following the earlier study, particularly internationally. Cooperative programs with Brazil, Mexico, Canada, and Italy in earth resources survey program have been set up and in the communications program with India and Canada, among others. Multilateral activities exist with the European Space Research Organization (ESRO) in joint planning for the first Spacelab payload, and with the USSR, Great Britain, France, and Japan in the Global Atmospheric Research Program (GARP). More than 100 foreign investigators have participated in the experimental program involving the Earth Resources Technology Satellite 1 data. These arrangements take many forms, each tailored to the specific needs and objectives of the research program and the desires of participating countries.

In response to a specific recommendation on the subject, the technology in instrumentation, data systems components, data analysis, etc., has moved ahead in many different ways. Sensor signature study has been a main thrust of the supporting research and technology program enhanced by data from the aircraft program and from the ERTS-1 and the Earth Resources Experiment Package on the Skylab missions. Wideband video tape recorders were developed for ERTS and Skylab. An extensive data collection system has been developed for the recently launched Synchronous Meteorological

Satellite (SMS) which, through the National Oceanic and Atmospheric Administration (NOAA), will have immediate operational utility. NASA plans to utilize a tracking and data relay satellite system based on commerically available and leased satellite services in the late 1970's and the 1980's, as recommended in the 1967-1968 Study.

Responsibility for the operational deployment of an aircraft communications and navigation satellite system has been shifted to the Department of Transportation/Federal Aviation Agency which is now formulating plans for a joint U.S./ESRO system (Aerosat) for North Atlantic traffic control.

During the World Administrative Radio Conference of 1971 considerable progress was made on the frequency spectrum allocation issues raised by the 1967-1968 Study. Details of this progress are given in Chapter V.

4. PROGRAM HIGHLIGHTS AND DIRECTIONS

The NASA Applications Program reflects the requirements defined in the 1967-1968 Study that it be extensive, coherent and selective if it is to achieve the benefits promised. In the early years, prior to 1968, the programs resources in manpower and funds were concentrated in communications and meteorology. In the years since 1969, the bulk of the resources have been directed to the earth resources survey, although the development of the Applications Technology Satellite F, a major project, also required significant resources. Since the 1973 decision by NASA to change priorities in the communications program as they related to early commercial utilization, resources applied to that program have dropped sharply. But emphasis is increasing in the earth and ocean physics program, with the development of the SEASAT project and in pollution monitoring with the development of Nimbus G; both programs will be significant NASA activities in the latter half of this decade.

A major NASA effort in the 1975-1980 period will be the continuation and extension of the capabilities and information acquired in the earth resources survey projects of 1969-1973 time frame. In addition, NASA is continously studying and exploring with the private and public planners and managers their potential utilization of space applications in anticipation of future, new applications and new use of space flight capabilities. This (1974) Summer Study is one such effort; Chapter X, Flight Mission and Resources Summary, provides a summary overview of the program plans.

5. ECONOMIC AND INSTITUTIONAL FACTORS

As the NASA Applications Program has grown and shifted in technical and discipline emphasis so too have the economic and institutional factors inherent in the establishment and funding approval of the programs and the individual projects which make up the programs. The Office of Management and Budget and Congress have increased interests in cost-benefit and cost-effectiveness studies and demonstrations. Conversely, as the 1967-1968 Study observes "...the conventional cost-benefit analysis approach is not suitable for judging technologies in the fluid, formative state." Chapter X provides an overview of NASA studies in economics.

Simultaneously, with other program shifts, the numbers of potential groups of users have grown and diversified. In meteorology, the NASA user/client was the Weather Bureau (the National Weather Services) who effectively represented all weather users. In the earth resources survey, there is today a host of user/clients, no one of whom speaks for all the others. Thus, NASA's institutional interfaces have become a major factor in establishing new or different programs and projects.

The importance of these factors is reflected in the fact that in this review each program chapter has sections on the cost/benefits activities in that program and on the institutional arrangements peculiar to that program. A summary of the cost/benefit activities has been prepared as a separate chapter (Chapter IX, Economic Analyses). Because of the unique relationships demanded by the different programs and their institutional constituents, there will be no attempt in this review to generalize on the subject of institutional interfaces.

CHAPTER III. THE EARTH OBSERVATIONS PROGRAM

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Concluded)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Concluded)

LIST OF TABLES

CHAPTER III. THE EARTH OBSERVATIONS PROGRAM

A. Weather and Climate

1. HISTORY

The U.S. Space Weather and Climate Program has the longest history in this country's endeavors to apply space techniques. Such efforts extend back many years before the creation of NASA in 1958. It is interesting to note in retrospect just how far we have come with this program since it has been underway. The first high altitude (100-mile) pictures of meteorological importance were taken by the U.S. Army using captured V-2 rockets on March 7, 1947. Improved pictures of cloud cover were obtained by the Naval Research Laboratory from Viking rockets from 1954 through 1956. Classic motion pictures showing the global sweep of cloud systems were recovered from an Atlas nose cone over the tropical Atlantic in 1959 and from still cameras aboard Aerobee rockets fired at Fort Churchill in 1960.

Although rocket photography provided an individual sample of the potentialities of weather observation from space, greater continuity of observation was essential for operational purposes. This was accomplished for the first time with the launch of TIROS-1 on April 1, 1960, 14 years ago. Research with the early television pictures led to many discoveries concerning the organization and movement of cloud patterns and their relationship to meteorological processes, and limited operational use of the television pictures in weather forecasting began soon after the launch of TIROS-1. Subsequent experimental satellites carried multichannel scanning radiometers. The radiometer data were applied in many different ways, including radiation balance studies, cloud cover mapping, the tracking of storms, the determination of surface temperatures and cloud top heights, the inference of mean tropospheric water vapor content, and the mapping of mean stratospheric temperatures and their associated circulation patterns.

Since from the operational standpoint the utility of meteorological data is inversely proportional to its age, it is vital to acquire and process the data in the shortest possible time and to make it available to end-users. This need was recognized with its related requirement for inexpensive, easily operated equipment and facilities. Accordingly, the Automatic Picture Transmission (APT) camera system was developed. By this means, picture data are transmitted directly to end-users within broadcast range, eliminating the need for

onboard storage and intermediate processing. This means that with a simple antenna, a receiver, and a facsimile recorder, the user can have real-time data on the local weather pattern. The first test of this system was provided by TIROS-8 launched in December 1963.

Throughout the TIROS project there was an extensive effort to develop the practical application of the data to both operational and research needs. Commencing with TIROS-1, techniques and procedures were developed for preparation of nephanalyses (cloud cover analyses) of all areas observed by the satellites. While these nephanalyses were vital to detecting significant meteorological developments in those areas of the globe where meteorological observations are scarce, the irregular pattern of coverage was such that the data from TIROS were used almost independently of worldwide weather analyses. With the advent of complete earth coverage provided by TIROS-9 launched in January 1965 and the centralized data processing system, the data became used as a regular and required input to the world weather analyses based on all types of meteorological observations.

On January 30, 1964, the Basic Agreement Between U.S. Department of Commerce and the National Aeronautics and Space Administration Concerning Operational Environmental Satellite Systems of the Department of Commerce was signed. This established a method for the implementation of the National Operational Meteorological Satellite System (NOMSS) with the Department of Commerce (DOC) — Weather Bureau having responsibility for the establishment and operation of NOMSS including reimbursing NASA for providing operational spacecraft and with NASA having responsibility for the conduct and funding of supporting technology for operational meteorological satellite development programs. The present NASA-DOC agreement is included in the Appendices volume.

To implement the operational program at an early date, the TIROS research satellite was modified into a wheel configuration and launched into a quasi-polar orbit to provide greater observational capability. These satellites were called TIROS Operational Satellites (TOS) during development, and are known operationally as Environmental Survey Satellites (ESSA); ESSA-1 was launched in February 1966.

The first geostationary satellite to carry a meteorological instrument — a Spin Scan Cloud Camera — was ATS-1, launched on December 7, 1966. Time-lapse "movies", made from images of the planetary disc taken approximately every 20 minutes from an altitude of 36,000 km, showed dramatically the short-term weather motions from space. New knowledge of wind, circulation, and wave features deduced from cloud motions, of interhemispheric

mass transport, and of mesoscale systems (such as squall lines, tornadoes, and other severe weather) was acquired. The development of a technique to determine winds by tracking clouds was of major importance; winds determined from ATS-3, after more than 6 years in orbit, are still being used operationally by National Oceanic and Atmospheric Administration (NOAA).

The NASA Nimbus series of satellites, with five successful launches to date, have been instrumental in developing the advanced instrumentation and measurement systems for increased capability of our operational system. The three-axis stabilized configuration gave greater flexibility in earth viewing beginning in August 1964.

Nimbus-3, launched on April 14, 1969, departed markedly from its predecessors by carrying three new classes of experiments. One, the Monitor of Ultraviolet Solar Energy (MUSE) experiment, monitored wavelengths important to the photochemical processes affecting the generation and destruction of ozone. A second, the Interrogation Recording Location System (IRLS), demonstrated the feasibility of locating moving platforms, such as balloons and buoys, and of collecting in situ measurements from them and determining atmospheric winds and ocean currents from their movements. The third class, represented by the Satellite Infrared Spectrometer (SIRS) and Infrared Interferometer Spectrometer (IRIS), was perhaps most dramatic in demonstrating the ability to sense remotely vertical profiles of temperature in the atmosphere. This is accomplished by suitably "inverting" spectral radiances measured over the 15-μm absorption band of carbon dioxide. The success was so dramatic that vertical profiles from SIRS on Nimbus-3 and Nimbus-4 were used operationally by NOAA, beginning in May 1969 and continuing until November 1972 when soundings from a new Vertical Temperature Profile Radiometer (VTPR) on the NOAA-2 operational satellite replaced them.

Nimbus-5, the most recent research and development meteorological satellite, was launched on December 11, 1972. It carried, for the first time, experiments sensing emission in the microwave part of the spectrum. Data from a single-channel Electrically Scanned Microwave Radiometer (ESMR) have demonstrated its potential for mapping sea ice through clouds and delineating precipitating cloud systems over the world's oceans. Data from the Nimbus-E Microwave Sounder (NEMS) have shown its ability to sound atmospheric temperature through overcast cloudiness, and it is already clear that the addition of microwave channels to infrared sounders of the future will markedly improve their accuracy.

The first three-axis stabilized prototype operational spacecraft, the second-generation Improved TOS, ITOS-1, was launched in January 1970. ITOS-D, which was launched in October 1972 and became NOAA-2 after being checked out and turned over to NOAA, was the first operational spacecraft to fly without a vidicon camera, relying instead entirely on scanning radiometers. It also carried the first operational sounder. NOAA-3, launched in November 1973, like NOAA-2 carries redundant eight-channel Vertical Temperature Profile Radiometers (VTPR), Scanning Radiometers (SR)(two channels, visible resolution 3.7 km, 11-μm resolution 7.4 km), Very High Resolution Radiometers (VHRR) (two channels, visible and 11 μm, resolution of both 0.9 km), and a single Solar Proton Monitor (SPM) and has the first direct readout capability of sounding data.

Skylab carried experiments for earth observations, including a multispectral camera, an infrared spectrometer, a multispectral scanner, and a composite active/passive microwave system. Although these experiments are primarily designed for earth resources survey, of particular interest to weather and climate is the active/passive radiometer-scatterometer-altimeter system, intended to measure ocean surface characteristics, such as roughness from which surface winds may be inferred.

Much of the spacecraft and instrument technology and many of the data applications techniques are utilized in the operational satellite system after they are tested and proven on experimental satellites. The above-mentioned evolution of vertical sounders from SIRS on Nimbus-3 and Nimbus-4 to VTPR on NOAA-2 is a good example. The evolution of meteorological satellites is illustrated in Figure III-1, where the first launched of each series is shown. As of April 1974, 17 experimental meteorological (not including manned or cooperative international) satellites and 13 operational meteorological satellites (and prototypes) have been successfully launched in support of the national objectives for a meteorological satellite system. Over 30 instruments have evolved directly into operational applications. Tables 1 and 2 in the appendix entitled "Meteorological Satellite Flights" present a summary of this record.

Another area in which NASA is involved in order to meet its obligations both nationally and internationally is that of meteorological sounding rockets. Meteorological rockets are a standard means of gathering atmospheric data above the upper limit of the balloon-borne radiosonde (about 30 km). Much valuable information has become available from rocketsonde observations for use in a variety of research studies, as well as for the derivation of high-altitude climatological and model atmospheres.

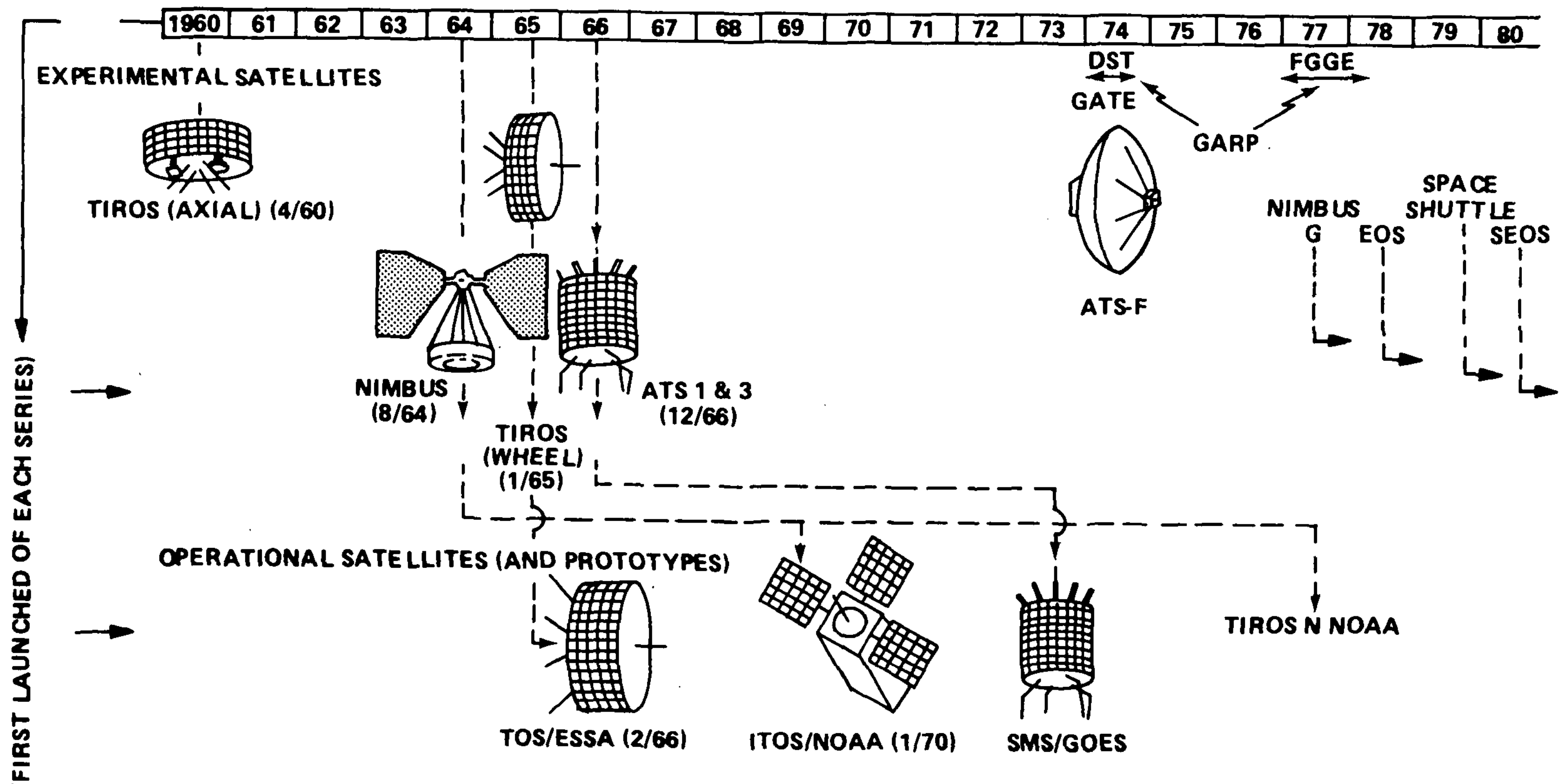

Figure III-1. Evolution of meteorological satellites (and other satellites with meteorological instruments).

The Global Atmospheric Research Program (GARP) can be traced back to October 1961 in a report to the President on the prospectus for developments in atmospheric sciences during the decade 1961 to 1971. This report, published in the National Academy of Sciences Publication Number 946, proposed the establishment of an International Atmospheric Science Program, an International Meteorological Service Program, and the World Weather Watch to provide global data for research and services. These ideas were adopted by the United Nations General Assembly on December 20, 1961, in a resolution on International Cooperation in the Peaceful Uses of Outer Space. Subsequent efforts of the World Meteorological Organization and the International Council of Scientific Unions led to the adoption of the name GARP in 1966 and a formal agreement on October 10, 1967. NASA has been a long time contributor to this program through its meteorological satellites and technical contributions to special observing systems. Key efforts have been made toward the GARP Atlantic Tropical Experiment (GATE) and Data Systems Test (DST) taking place in 1974.

It has been almost 7 years since the National Academy of Sciences and National Academy of Engineering (NAS/NAE) conducted a summer study on the "Useful Applications of Earth-Oriented Satellites." Since that time NASA has responded to the recommendations made by the panels and the Central Review Committee. Specifically in weather and climate these are:

a. NASA should continue to direct its meteorological satellite program to meeting the observational requirements of the GARP and the World Weather Programs. NASA should continue to support and expand its space technology programs aimed at securing the quantitative, worldwide, general-circulation atmospheric information required by the meteorological community for mathematical models of the world weather system.

NASA's support of this recommendation is demonstrated by the preceding history as well as in its present program, which is discussed in Section III.A.3. "Implementation."

b. The geosynchronous meteorological satellite is a more effective platform than it was first considered to be. NASA should proceed to develop a fully integrated meteorological geosynchronous satellite to be available by 1971. Both visible and infrared images should be available in real time. Display equipment to present time-lapse views of these data should be developed.

ATS-3 has been providing data from geostationary orbit since 1967. NASA efforts in this area have been focused on the development of a fully integrated satellite having both visible and infrared images, data collection, and direct readout capability. This Synchronous Meteorological Satellite (SMS) will be available in 1974.

c. NASA's infrared and microwave vertical temperature sounding programs should be reoriented to include both polar and geosynchronous satellites, and should be developed into integrated systems capable of satisfying known data requirements for long-range numerical weather forecasting. Research and development should be started immediately on techniques that show promise for obtaining soundings of the atmosphere below clouds, such as microwave radiometry and the radio occulation technique.

Major efforts to provide sounding on both polar and geostationary satellites have resulted in the VTPR on the NOAA satellites beginning in October 1972, and modifications to Visible Infrared Spin-Scan Radiometer (VISSR) on SMS/Operational Environmental Geostationary Satellite (GOES) are underway to make that instrument an imager/sounder on future GOES missions.

Nimbus-5 has demonstrated the first microwave sounding and work continues in this area.

More detail on present efforts is contained in Section III.A.3, "Implementation."

d. A high priority should be assigned to development of a suitable balloon electronics package that fully meets the lightweight requirements needed to prevent its being a hazard to aviation. A simple, lightweight, low-cost, yet meteorologically useful balloon package must be developed.

NASA acted in a consultant role in the French Meteorological Satellite (EOLE) efforts. Additional efforts have been directed toward the Tropical Wind, Energy Conversion, and Reference Level Experiments (TWERLE) system discussed in Section III.A.3.c.(3)(b), "Nimbus-F."

e. Develop and deploy operationally a data-collection relay satellite system, to provide for the interrogation and collection of data from large numbers and types of widely distributed data platforms, such as hydrologic gauges, meteorological balloons, oceanographic buoys, and other sensors, and for the relaying of those data to specified data-processing centers.

The SMS/GOES and TIROS-N have been designed in concurrence with this recommendation.

2. GOALS AND OBJECTIVES

The extensive history of development and system evolution has served to focus the NASA program in Weather and Climate into the following long range objectives:

- Operational Support
- Weather Prediction
- Weather and Climate Modification
- Weather Danger and Disaster Warning
- Process and Interactions of Physical Factors Affecting Weather and Climate

- Operational Support. Support the development of the National Operational Meteorological Satellite System. This includes development of advanced instruments and spacecraft for ultimate application to the operational system, together with the engineering and management of the current operational hardware. This is done to effect those changes that will improve and capitalize on the system's capabilities. The history of the program shows the evolution of over 30 instruments into operational applications.

Key efforts are in the operational satellite projects of ITOS and SMS and in the Operational Satellite Improvement Program discussed in Section III. A. 3, "Implementation." In addition, research and development spacecraft and research and technology efforts are playing a vital role in developing the technology needed for improving the operational system.

- Weather Prediction. Develop space technology for determining the vertical structure of the atmosphere globally which, when supplemented by simulation techniques, models, and conventional observations, will provide the required data for weather forecasts with emphasis on large scale, long-term phenomena. Accurate weather prediction is the major goal of the science of meteorology. Meteorology deals with a broad range of events in both time and size, from rapid turbulent fluctuations produced by tornadoes to changes in climate occurring over many years. This is illustrated in Figure III-2. Atmospheric events on every scale are important.

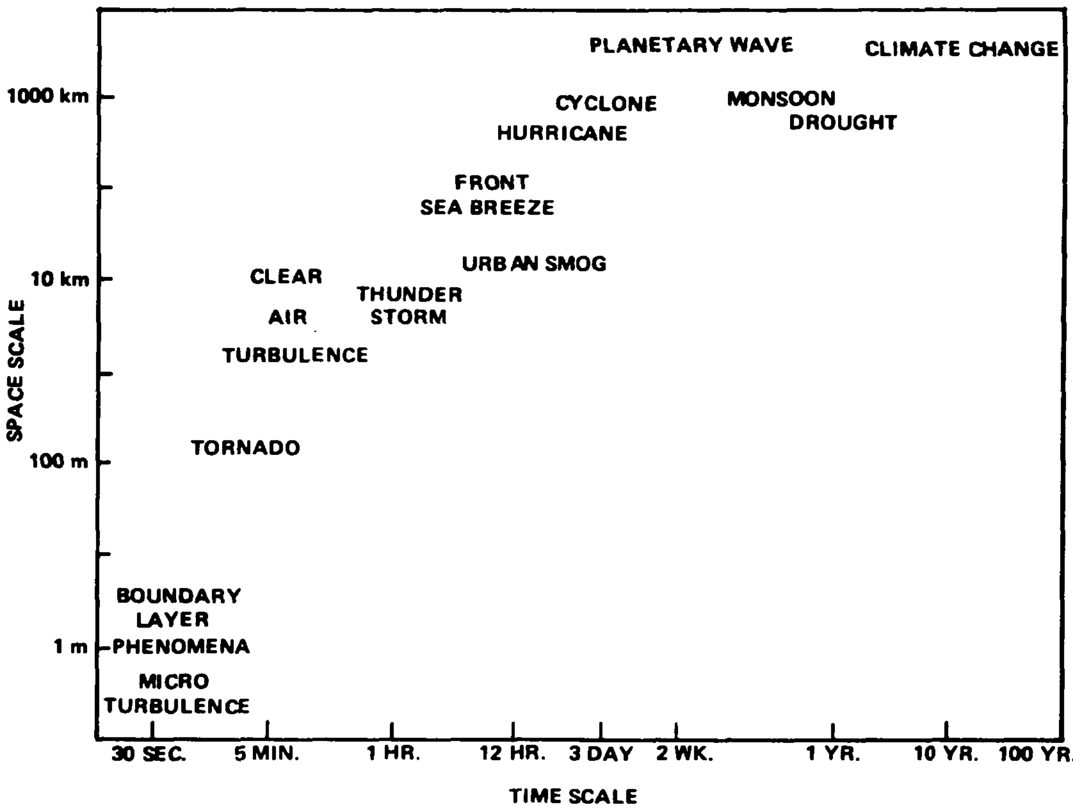

Figure III-2. Time and space scales of meteorological phenomena.

Weather prediction based on analytic models is a relatively recent development, stemming from the period immediately following World War II when high speed electronic computers made it possible to solve the difficult mathematical formulas describing atmospheric motions and their behavior. But a further obstacle — that of inadequate observations over about 80 percent of the earth's area, i.e., the oceans and some portions of the land — stood in the way of extending the range and accuracy of forecasts. The atmosphere acts as a single physical system in which disturbances in one region will affect conditions in distant regions within a period of several days. Therefore, observations are required over the entire globe for long range weather prediction.

The cost of obtaining adequate worldwide data by ships, aircraft, and other conventional means is prohibitive. The earth-orbiting satellite has afforded an economically feasible global-observing capability. Recognizing this opportunity, the world meteorological community has initiated an international World Weather Program. The United States plays a significant role in the World Weather Program, with certain national objectives:

a. To improve the United States weather services by increasing the accuracy and extending the time and scope of weather predictions.

b. To develop tools for assessing the consequences of man's pollution of the atmosphere.

c. To establish new dimensions of international activity and durable bonds of trust among the nations of the world, stemming from a universal need for improved weather service and a growing concern for environmental quality.

NASA plays an important role in support of the United States participation in these activities. Early efforts to observe and monitor the earth's weather from space have proven the feasibility of providing reliable, day and night observations of the atmosphere on a daily and global basis.

Advanced instrumentation seeks the new knowledge that is needed in this area; however, the greatest effort today is in the development of numerical models and computer techniques to capitalize on the data available both to show what forecast improvements are presently possible and what further measurements are needed. This is a very important feedback loop in advanced developments.

- Climate and Weather Modification. Apply space-acquired data from remote sensors, data collection systems, and in-flight experiments requiring unique orbital conditions (such as a gravity-free environment) to the development of models and establishment of mechanisms for the rational examination of deliberate and inadvertent means for modifying weather and climate. The field of weather modification probably represents the ultimate objective for meteorology whereby mankind could alter the weather to suit its own desires and needs. NASA is not conducting weather modification experiments as such. However, flight programs with improvements in spatial and time detail of observations will support weather modification experiments.

In the area of longer-range climate forecasting encompassing weeks to months with high utility to the agriculture section of our economy, gross measurements of the earth's radiation budget have been provided and efforts have begun to yield primitive climate models. Variations of the solar input, ocean-atmosphere interactions, variability in atmospheric gas and particle constituents, and changes in terrain features all contribute to the character of the climate. Measurements of these quantities are necessary to assess their relative contributions. Immediate goals are to develop the total radiation budget of the earth including the solar input and the earth radiation together

with an assessment of the effect of gaseous and particle constituents on the radiation balance. This will permit initiation of improved climate models. Continuing research in atmospheric constituents and pollution should shed light on the extent and degree of inadvertent modification as a result of man's industrial and urbanization endeavors. Remote sensing from space can provide useful information on the atmospheric conditions prior to and after weather modification experiments. With the improvements planned for the geostationary satellites, the effects of such experiments may be assessable locally.

One aspect of weather modification amenable to space research is the field of cloud physics research. If such experiments could be conducted in space, under low- or zero-gravity conditions, great progress could be made in the field of cloud physics through the controlled conditions in such experiments. The forthcoming Space Shuttle affords a laboratory with the low-gravity conditions required. This idea has been receiving enthusiastic support from the principal cloud physics laboratories of the country. An immediate goal is to define such a laboratory. Future effort will provide a design and the developments required with the longer range objective of producing a Shuttle-compatible cloud physics laboratory to be operated in orbit.

- Weather Danger and Disaster Warning. Develop and establish a system for continuous observations of atmospheric features to permit early identification and quantitative measurement of atmospheric conditions conducive to the formation of severe atmospheric phenomena (e.g., thunderstorms, tornadoes, hurricanes, etc.) to serve as a basis for timely warning to the public. For problems in current weather dissemination, successful development and deployment of APT systems permit receipt of cloud cover and weather analyses by local receiving stations. In addition, experimental ATS satellites have shown the high utility of cloud cover data from geosynchronous altitude but have been limited to daylight operation. These satellites have also demonstrated the capability of relaying weather information routinely between major forecast centers. The soon-to-be-launched geostationary satellites, SMS-A and -B, followed by the operational version, SMS-C/GOES-A, will provide continuous cloud cover data, both day and night, as well as transmission of local weather information to appropriate local ground receivers on a fully operational basis. These satellites will also be capable of collecting remote, in situ measurements of weather and related phenomena through their data collection capability. The use of specialized ground processing and display equipment for easier and faster utilization by local users will also be demonstrated.

There are pressing needs in weather danger and disaster warnings. Such dangers are characterized as severe local storms, heavy rainfall or cloudbursts, floods, and tornadoes. The key to identifying, monitoring, and tracking severe local storms is a geostationary satellite able to provide high resolution data at very frequent intervals and in real time. The advanced study and planning of the necessary optics, sounding capability, and data collection and relay features of such a geostationary satellite will make a substantial contribution in these areas. Of more immediate application will be current efforts to develop a sounding capability from geostationary altitude to be applied to a future goestationary spacecraft and the initial experimental measurements from a meteorological imager flying on the ATS-F satellite this summer. This effort in weather danger and disaster warning contains a great potential payoff for the largest segment of our population.

One problem which must be faced in severe storm forecasting is in the manner by which all the data we will soon be capable of producing can be assimilated and displayed. It will be necessary to automate the process with computers and still maintain the human interface with the data to provide the maximum utility. In recognition of this problem, a study of the necessary developments required has begun. This will be a long term endeavor requiring significant advances in computer technology and display devices.

- Processes and Interactions of Physical Factors Affecting Weather and Climate. Investigate fundamental atmospheric processes and interactions on various temporal and spatial scales through the observation of the structure, composition, and energetics of the atmosphere for the purpose of effectively applying space capabilities. While the effects of both manmade and naturally occurring air pollutants in the troposphere are poorly understood on regional and global scales, the importance of some of the pollutants in terms of global climate — because of their influence on the earth radiation budget — has been recognized for some time. The effects of the pollutants may result from some property of the emitted material, e.g., the long lifetime and infrared radiative properties of carbon dioxide, or they may be effects that are related to the properties of the materials after they have undergone some chemical or physical change in the atmosphere. An example of this second category would be the radiative effects of particles that have been formed in the atmosphere from sulfur or nitrogen oxides. At the present time, the global distribution of these gases is not well known. Remote sensing from satellites offers the advantage of measuring tropospheric air pollutants on a global scale with one instrument on a continuous basis. The distribution of carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), methane (CH_4), ammonia (NH_3), and aerosols will be measured in the later part of the decade by instrumentation on Nimbus-G.

To analyze the energy interactions between atmospheric levels and of solar-terrestrial relationships, the interactions of mechanical, radiation, and chemical energies between the lower and upper regions of the atmosphere and its interaction with solar radiation and distribution of minor constituents are investigated. Measurements of the absolute solar irradiance and the solar constant from balloons and high altitude aircraft will be made in a search for solar variability over a period of the 11-year solar cycle. Satellite and rocket measurements of ozone, water vapor, and the neutral thermodynamic structure of the stratosphere and mesosphere will be analyzed to determine the interactions of photochemistry, radiative processes, and atmospheric dynamics in producing, transporting, destroying, and exchanging these minor constituents between the upper and lower atmosphere.

Little is known about the important processes for destroying ozone and the role of atmospheric motions (especially vertical motions) in generating the transient ozone features. The Nimbus-4 Backscatter Ultraviolet (BUV) atmospheric ozone experiment has produced nearly 3 years of ultraviolet solar irradiance data which are being used to infer the global distribution of atmospheric ozone. The ozone distribution subsequently can be used to investigate transport and photochemical processes in the stratosphere.

Emission spectra of the earth-atmosphere system from balloons at high spectral resolution over a broad spectral range will be used to obtain a better knowledge of the infrared optical properties of the atmosphere, including band absorption in the atmospheric window region, and the optical properties of clouds. These measurements could be employed to study improved vertical sounding techniques by optimizing spectral intervals and resolution for future operational systems.

3. IMPLEMENTATION

Management responsibility for implementation of the Weather and Climate Program so as to meet the program goals and objectives is vested in NASA Headquarters, Office of Applications, and in particular, in the Earth Observations Division. The Goddard Space Flight Center, which has been designated as the lead center for meteorology, makes program recommendations to NASA Headquarters based on its liaison within Goddard, with other NASA centers involved in the program, with the National Oceanic and Atmospheric Administration, with weather services and research groups within the Department of Defense, with universities and industry taking part in the program, and with the international community.

The organization of the program to meet the long range Weather and Climate Program objectives recognizes the phased development of application techniques through four stages:

- Establishment of quantitative relationships between observable parameters and geophysical variables.

- Development, test, calibration, and evaluation of eventual flight instruments in experimental space flight missions.

- Demonstration of the operational utility of specific observation concepts or techniques as information inputs needed for taking actions.

- Deployment of prototype and follow-on operational earth observation systems.

In the Weather and Climate Program, eight research and development (R&D) elements have been identified, leading sequentially from a fundamental investigation to an application in an operational satellite system. The R&D elements are listed generally in time sequence and described below. The numbering scheme is used as an aid in management of the program.

(1) Basic Studies — This element concerns fundamental studies of physical laws and processes necessary before the application of space technology to an environmental problem can be pursued. Key current examples are studies to improve our knowledge of atmospheric radiative transfer in particulates and minor constituents and studies of ocean-atmosphere interactions for the purpose of identifying observables that can best utilize space in developing techniques for predicting climatic change.

(2) Development of Observing Concepts — This element concerns activities such as "signature studies," leading to new observing concepts in pursuit of program objectives. A key thrust of this element is the development of geostationary applications, e.g., weather disaster detection and warning and pollution monitoring.

(3) Sensor and Spacecraft Technology Development — This element concerns the development and/or adaptation of space technology necessary to implement needed observing concepts.

(4) Future Experiments Design and Development — This element concerns the development or modification and validation of sensory systems to a high level of confidence before committing them to space flight.

(5) Data Processing and Display Technology Development — This element concerns developing improved capabilities to handle large quantities of quantitative (i.e., digital) data. The need for such improved capabilities is brought about by advanced quantitative sensors, having increasingly high spatial resolutions and requiring multispectral analysis techniques with data simultaneously acquired in several different spectral bands.

(*) Flight — This element concerns the focus of all activity carried out under the preceding elements, namely, the flight of sensors, either experimental in nature on R&D missions or proven designs on operational satellites, for the benefit of man in his relationship to the (meteorological) environment.

(Note: Inasmuch as this is the only element not applicable to projects covered by Research and Technology Operating Plans (RTOP), an asterisk is placed in the parentheses at the beginning to maintain compatibility with the RTOP numbering system.)

(6) Interpretation and Applications of Observations — This element is perhaps the most important of all (without which all else would be wasted) — the analysis and interpretation of the sensory data for the purpose of applying them for the benefit of mankind.

(9) Multielement, Advanced Planning, and/or Advanced Systems Studies — This is a special element applying to those projects which address two or more of the other elements, including advanced planning activities and advanced systems studies.

(Note: Numbers (7) and (8) are omitted to maintain compatibility with the Agency-wide RTOP numbering system where they are reserved for future use.)

Each of these program elements may contribute to one or more of the program goals and objectives. To provide structure to program evolution, these elements are organized around three broad areas:

a. Research and Technology

b. Complementary to Flight Projects

c. Flight Projects

There are currently four programs included in the Research and Technology area:

a. Weather and Climate Supporting Research and Technology

b. Pollution Monitoring Supporting Research and Technology (Meteorology)

c. Advanced Studies

d. Shuttle Experiment Definition

The Complementary to Flight Projects — Advanced Applications Flight Experiments (AAFE), Operational Satellite Improvement Program (OSIP) and Global Atmospheric Research Program (GARP) — are not individual flight missions but rather are research and development activities that directly support or "complement" the flight missions.

There are two types of satellite flight missions. One type includes R&D missions flying new and advanced sensors for the purpose of proving the scientific concept, technological approach, and/or data utility before incorporating the sensors into an operational system. This type of mission is funded by NASA along with operational prototypes. The second type of mission includes fully operational satellites such as ITOS/NOAA and SMS/GOES. These are funded on a reimbursable basis by the user agency (NOAA). In addition to satellite flights, aircraft and rocket flights play an important role in the Weather and Climate Program.

a. <u>Research and Technology</u>

(1) Supporting Research and Technology. Efforts in the Weather and Climate Supporting Research and Technology Program build upon expertise developed over the past with empahsis on the following:

- Determination of meteorological parameters in the data obtained from remote measurements by satellite, aircraft, rockets, or other means.

- Development and demonstration of methods of utilization of such data for meteorological applications.

- Development of spacecraft and sensor systems and components.

- Development of experimental techniques for the remote sensing of atmospheric constituents.

- Studies of the interaction of atmospheric pollution with solar variations and the overall effects on the heat budget of the earth.

- Investigations and development of applications of satellite temperature profile data in numerical circulation models.

- Research on the degree of relationship that can be expected to exist between large scale (synoptic) meteorological parameters and mesoscale systems. The objective is the development of improved satellite data analysis techniques for mesoscale phenomena with primary emphasis on data from the geostationary observing systems.

- Aircraft support to satellite instrumentation development by providing early flight opportunities to provide ground truth and early data analysis. The basic aircraft for this support will be the Convair 990 and U2.

- Supporting laboratory and global studies primarily of minor atmospheric and stratospheric constituents. These studies will incorporate turbulence models for numerical integration of wind and temperature fields that will be used to drive photochemical dispersion models to study the dispersion of air pollution.

- Research on the application of satellite system technology to the problem of tornado detection and warning and possibly to the intensification of larger scale meteorological systems, leading to development in cooperation with NOAA of a Severe Storm Monitoring Program based on conventional and satellite techniques.

- A concerted effort to develop a centralized computing system with the necessary capability to capitalize on the meteorological data presently available and that soon to be available. NASA, in order to continue its

leadership role in meteorological applications of space, must assure full utilization of the information received as well as demonstrate the future developments required in sensors across the entire electromagnetic spectrum. This can only be accomplished through an iterative process based on data analyses and application demonstrations.

(2) Advanced Studies. Studies are currently underway for the following planned future missions.

(a) Geosynchronous Stabilized Imaging Sounder Mission Study. Three-axis stabilization in geostationary orbit affords certain advantages that permit important improvements in sounding and imaging capability over a spinning instrument of equal aperture size. A three-axis stablized instrument can continuously view the earthdisc while a spinning instrument necessarily must spend a large part of the time uselessly viewing space. For the geostationary situation, the earth subtends approximately 18 degrees so that a scan efficiency of about 20 to 1 results. In addition, more effective scan modes can be utilized. The field of view can be constrained so that a selected area can be scanned, whereas a spinning instrument can be constrained in only one dimension.

An Advanced Atmospheric Sounder and Imaging Radiometer (AASIR) is under development as part of the Advanced Application Flight Experiments Program discussed later. An advanced study of the three-axis sounding/imaging concept was begun in FY-74. That study will investigate different types of spacecraft and their associated stabilization, weight, power, and telemetry characteristics with respect to their suitability for flying an instrument like the AASIR and with respect to their future applicability as second generation operational geostationary satellites.

(b) Oceanography and Meteorology Mission Study. Basic meteorological research from satellites has been supported by flight opportunities on the Nimbus series of spacecraft. With the phaseout of the Nimbus program with flights F and G, the meteorology research program can utilize the Earth Observatory Satellite (EOS) for near-earth orbit flight opportunities. The EOS system will provide a space platform for testing experimental sensors and spacecraft subsystems for acquisition of data for environmental research and for development of space applications in earth resources, environmental management, and meteorology. Emphasis is placed on combining instruments into payload combinations which will complement one another synergistically. EOS will thus not only continue the terrain survey and meteorological research previously provided by Earth Resources Technology Satellite (ERTS) and Nimbus, but would initiate new programs in the study of oceanographic phenomena and environmental quality.

Perhaps the greatest expected breakthroughs in obtaining meteorological data from space can be expected in the microwave spectrum. The EOS spacecraft concept, which has been under study and preliminary development for several years represents the best foreseeable manner in which the next generation of microwave imagers and sounders can be expected to fly.

Interdisciplinary measurements from space of importance to meterology that are considered feasible in the EOS time frame include:

1 Sea surface phenomena; temperature, roughness, composition (chemical, biological, particulate), phase (ice/liquid), pollution, and currents.

2 Structure and phenomena of the atmosphere above 30 km; temperature and composition (water vapor, ozone, trace constituents, dust).

3 Cloud structure and composition/ ice versus liquid clouds, thickness, density of condensed water, drop size parameter, precipitation, and cloud top pressure level.

4 Spectral, spatial, and temporal characteristics of significant earth surface features; soil moisture, snow/ice survey, and thematic mapping (visible and infrared).

5 Interactions between different levels in the earth atmosphere system (utilize measurements performed in other areas).

6 Atmospheric pollution; gaseous and particulate.

A study has begun to define a joint meteorology/oceanography mission for flight on EOS.

(c) Synchronous Earth Observatory Satellite (SEOS). Monitoring of natural disasters such as hurricanes, tornadoes, forest fires, floods, frost, and disease and insect crop damage is recognized as one of the key national problems to be addressed over the next decade.

It has already been demonstrated that remote observations can be used to help monitor and ameliorate the effects of such disasters. This has been particularly true in the case of hurricances where warning made possible by their early detection and tracking have largely been responsible for sharply cutting the number of associated deaths even though the number of people in affected areas has markedly increased.

Technology is now available for application to other natural disasters which affect a broad range of the population. Such technology reflected in the capabilities of SEOS will allow it to make important contributions to monitoring natural disasters and to the study of other important national problems. These range from predicting the occurrence of severe weather phenomena such as tornadoes, to monitoring potential manmade disasters such as oil spills and providing operational information on the productive locations for finding fish in the oceans. The unique capabilities of SEOS for nearly continuous observations with good spatial resolution will open new research opportunities for a broad segment of the academic community and new avenues for international cooperation.

It is believed the requirements for such monitoring can be met by combining observations made with a large infrared/visible telescope and an infrared vertical atmospheric sounder in a geostationary orbit with appropriate ground-based observations collected by the satellite system. To observe the desired regions on the earth the complete spacecraft will be pointed by a three-axis control system having a slew capability. Slow, highly stable, slew motions will be used to obtain the slow scan, wide area coverage requirements.

SEOS will provide the complementary research capability from geostationary orbit to the low altitude polar orbit observations of EOS.

(3) Shuttle Experiment Definition. A number of R& D requirements may be accomplished in Sortie missions of from 7 to 30 days duration and at orbital altitudes of less than 926 km. In the present Weather and Climate Program, the initial activity has often required extensive aircraft "Sorties," such as those that have been conducted with the NASA Convair 990; for example, to determine surface wind speeds from microwave radiometric observations and cloud composition from spectrometric observations. This is followed by experimental flights of sensors and other instruments on observatory spacecraft such as Nimbus. The Shuttle "Limited Mission" capability would appear to be particularly useful in the development of passive microwave radiometry systems for all weather ocean monitoring and active microwave radar systems for various aspects of earth and ocean survey.

The development and application of weather modification techniques requires the understanding of numerous microphysical processes and their relation to such aspects as the growth of cloud particles and its role in cloud dynamics. In laboratory research, the particles extended from millimeter rain drops and ice crystals down to submicrometer condensation nuclei. Their study involves problems of drop dynamics, growth, collision, and

electrical properties. The space laboratory provides for long duration observation of the behavior of suspended particles and for the elimination of artificial supports and the attendant thermal, electrical, and mechanical contamination of the droplets.

(4) Other Studies of Interest to Weather and Climate — Sea State Satellite for Ocean Physics (SEASAT). A significant amount of planning is presently underway for a program in oceanography. The most significant activity at present is in the development of SEASAT, now receiving serious consideration for new-start authority. In all such planning and implementation, the direct interface between oceanography and meteorology must be recognized. The commonality of the measurements desired and the interactions of the physical states of both the oceans and the atmosphere require close coordination of flight instrumentation, data processing, and numercial modeling techniques.

The SEASAT spacecraft will be dedicated to ocean-dynamics applications in the later seventies and early eighties, with a prime goal to develop and demonstrate space techniques that will contribute to the development and validation of predictive models for ocean surface conditions and ocean circulation.

The following instruments are being considered:

Altimeter	Sea Surface Topography Wave Height
Scatterometer	Sea Surface Winds/Sea State
Imaging Radar	Wave Spectrum versus Direction
Microwave Radiometer	Sea Surface Winds/Sea State Sea and Pack Ice Altimeter Propagation Path Correction
Visible-Infrared Imager	Sea Surface Temperature Sea and Pack Ice

Onboard processing and self-pointing are required to support these sensors. Laser corner cubes, C-band radar transponders, and satellite-to-satellite transponders are planned to provide the highly accurate all-weather and long-arc coverage for orbit determination.

b. <u>Complementary to Flight Projects</u>

(1) Global Atmospheric Research Program. Under the guidance of the World Meteorological Organization, and the International Council of Scientific Unions, the Global Atmospheric Research Program was formed as a scientific endeavor whose central goal is a study of those physical processes that are essential for an understanding of the behavior of the atmosphere. This will lead to increasingly accurate weather forecasts over periods from 1 day to several weeks and also to a better understanding of the world's climate.

The United States has been involved in the planning and activities of GARP for over a decade. GARP must be looked at as a long term program consisting of step-by-step experiments leading to the ultimate goal of understanding the earth-atmosphere system for improved weather forecasting. Currently, there are three major milestones in which NASA plays a vital role. Two of these, the Data Systems Test and the GARP Atlantic Tropical Experiment take place during CY-1974; the third is the First GARP Global Experiment (FGGE) scheduled for 1977 through mid-1978.

The detailed planning for the U.S. participation in the FGGE is a NASA responsibility. Present plans for the Global Observing System include: (a) the improved World Weather Watch (WWW) surface based systems; (b) the satellite subsystem composed of five geostationary spacecraft, two SMS's from the U.S. and one each from the U.S.S.R., Japan, and the European Space Research Organization (ESRO), and two polar orbiting spacecraft, one from the U.S. and one from the U.S.S.R; and (c) special observing systems involving balloons and buoys with satellite data collection. A detailed discussion of the rationale and plans for the program are contained in the extensive GARP reference documents listed in Section III.A.7.

(2) Operational Satellite Improvement Program. The OSIP provides for adapting the technological advancements achieved under NASA's research programs to upgrading and improving the operational satellite systems.

An example is the development of an atmospheric sounder for the Geostationary Operational Environmental Satellite. A study has produced good results, and development activities have been initiated to produce a more versatile and useful instrument than had been expected. The engineering model of the VISSR will be modified to produce a new instrument called the VISSR

Atmospheric Sounder (VAS) that will detail observations of local conditions to permit improved weather predictions and better warnings of severe, short duration weather events such as thunderstorms and tornado-producing cloud systems. The concepts on which this instrument are based have been substantiated by results obtained by the Nimbus-5 research instrument called the Infrared Temperature Profile Radiometer (ITPR).

Numerous smaller tasks are carried out under this program. Not all of them are directly connected with improving spacecraft sensors. Some are aimed at improving components of sensors (such as detectors to be used in instruments), or at improving the accuracy of sensors (such as ground test and calibration techniques), or at developing improved data analysis methods (both for data utilization and applications demonstrations and for guiding further instrument improvements), or at improving the supporting spacecraft systems.

(3) Advanced Applications Flight Experiments. The AAFE Program has been effective in developing experimental instrumentation for future missions in the various applications disciplines. Annually, instrument proposals that exhibit potential usefulness in applications are selected for development under the AAFE Program. Development of these instruments continues only so long as there is promise of potential benefit and until their usefulness and effectiveness for becoming flight candidates are demonstrated. Development is accomplished without commitment to a specific spacecraft missions, and those not meeting the projected or anticipated research results are eliminated prior to the expensive flight development phase.

A number of AAFE sensors, now being developed as candidates for the mid- and late-1970's missions of Nimbus-G, EOS, and the Shuttle, will provide measurements of ocean and earth parameters such as sea state, sea surface temperature, sea surface color, effluents in estuaries and streams, and the multispectral characteristics of surface materials.

The development of a 16-inch aperture, three-axis stabilized Advanced Atmospheric Sounder and Imaging Radiometer was begun as a result of the FY-74 AAFE solicitation. Other efforts are devoted to developing instruments for determining the earth radiation budget; instruments for measuring soil moisture, an important parameter in agricultural, geological, and meteorological investigations; analog-digital multispectral image processing and multispectral techniques for the rapid analysis and recognition of multispectral signatures; and active microwave instruments.

c. Flight Projects. This section is intended to give a brief picture of the currently approved NASA flight program.

(1) Polar-orbiting Operational Satellites. The Improved TIROS Operational Satellite has replaced the original TIROS Operational Satellite which provided daytime global viewing and direct readout to local ground stations without interruption since February 1966. The ITOS system provides global data both day and night. The prototype ITOS satellite was launched on January 23, 1970, as ITOS-1. The ITOS system will be maintained with launches as needed, projected at about 1-year intervals. Satellites of this series, beginning with NOAA-2, include a capability for obtaining vertical temperature and moisture profiles of the atmosphere. Addition of the VTPR system completes the first operational system for sounding the atmosphere twice daily on a near global basis, a major objective of the national operational environmental satellite program. The VHRR system provides high resolution imagery in both the visible and infrared portions of the spectrum (1 km under satellite track). The VHRR operates mainly as a local readout subsystem to specially equipped locations, with limited high resolution storage capacity for data from selected remote areas. The vidicon camera systems in use on the earlier ITOS have been discontinued; their daytime viewing is performed by the combined day and night viewing and temperature sensing SR which provides global image data. The primary sensor complement (SR, VHRR, and VTPR) is expected to continue on the polar-orbiting satellites into FY-1977. The APT service will continue with the signal provided by the SR; day and night service is available from the SR which observes in both the visible and infrared spectra. To receive SR data, a conventional APT ground station recorder must be modified, and the details of the modification vary with the manufacturer and type of recorder. An SPM is carried as a secondary sensor.

The ITOS series of operational environmental satellites will be replaced by a new series, the prototype of which is designated TIROS-N, in the late 1970's. The existing operational meteorological satellite system is not adequate to meet the requirements for increased accuracy, improved spatial resolution, additional spectral intervals, and improved data handling and communications that will be required for the second half of the 1970's and the early 1980's. These requirements will necessitate the addition of large optical systems, an increased number of channels, and onboard digital data handling to preserve the data accuracy.

The primary mission of the third generation operational meteorological spacecraft will be to provide an economical platform for the operation of the advanced instruments used in making global daytime and nighttime observations of the earth's cloud cover, measurements of sea surface temperatures, and temperature and water vapor soundings of the earth's atmosphere. Secondary mission objectives are to receive, process, and retransmit data from free-floating balloons and buoys distributed around the globe and to measure proton and electron flux near the earth.

More specifically, the objectives are to provide an advanced operational meteorological observation capability by provision of the following:

- A stable platform capable of maintaining an earth pointing accuracy of better than ±1 degree in all three axes, with motion rates of less than 0.035 degree/second with attitude determination to an accuracy of 0.1 degree predictable in advance to 0.2 degree.

- Daily global daytime and nighttime cloud cover imaging in stored and direct readout modes with a resolution of 4 km in four spectral regions.

Visible	0.5 to 0.7 μm
Near Infrared	0.75 to 1.0 μm
Infrared Window	10.5 to 12.5 μm
Water Vapor	6.5 to 7.0 μm

- Very high resolution (1-km) global daytime and nighttime direct readout cloud cover images on a regular daily basis with a capability of a limited area stored data mode. Spectral regions for the 1-km data will be the visible, near-IR, and IR window channels. The resolution of the water vapor channel will remain at 4 km.

- Global cloud cover data which are contiguous at the equator with a zenith angle of less than 65 degrees at the point of contiguity.

- Daily global atmospheric soundings of temperature, water vapor, and ozones as follows:

Temperature

Range: Surface to 1 mb

Accuracy: ±1°K over eight layers from the surface to 1 mb (the eighth extends from 10 mb to 1 mb)

Geographical distribution: Global

Water Vapor

Range: Surface to tropopause

Accuracy: 20 percent (Desired, 10 percent)

Geographical distributions: Same as for temperature

Ozone

Range: Total amount, 0.15 to 0.60 cm

Accuracy: ±0.01 cm

Geographical distributions: Same as for temperature

- Receipt, processing and retransmission of data from fixed platforms and from free-floating balloons and buoys to measure temperature, humidity, pressure, wind speed (to 1 to 3 meters/second, rms) and location (to 5 km, rms).

- Reduced delays between the time data are obtained and their dissemination by eliminating the "double blind" orbits.

- Improved data handling capabilities to allow sea surface temperature measurements to an accuracy of 1°C absolute and 0.5°C relative.

- Operational data on a continuous, regular daily basis for a spacecraft operational lifetime of 2 years.

- Solar proton and total energy deposition monitoring of the flux activity near the earth.

(2) Geostationary Operational Satellites. The Synchronous Meteorological Satellite will be first in a series of spacecraft which will comprise the eventual Geostationary Operational Environmental Satellite system. NASA is responsible for the spacecraft and ground system design and development, for the launch vehicle, for launch operation, for initial satellite checkout in orbit, and for spacecraft evaluation. The DOC-NOAA is responsible for the operational phase of the satellite including determining the need for replacement, for operation of the ground system, and for the acquisition, handling, and processing of the satellite data. The first of these spacecraft, SMS/GOES, is scheduled for launch in 1974.

The primary mission of SMS is to provide up-to-the-minute weather information through the use of high resolution visible and infrared images. The high resolution of the VISSR, coupled with the ability to obtain a new full earth picture each 20 minutes, presents the meteorologist with a powerful instrument for making observations of mesoscale phenomena.

The visible spectrum pictures will permit meteorologists to view during daylight, virtually in real time, the evolution and motions of storms and other atmospheric phenomena. Analysis of the reflection of the sun on the surface of the sea may lead to the ability to infer surface wind velocity and height of waves thus providing important data for maritime interests. The infrared pictures will extend storm tracking capability through the night. In addition, sensing in the infrared will allow temperature measurements to be made of cloud tops and in cloud-free portions of the terrain or ocean surface on a 24-hour basis. Such data will provide additional inputs for mathematical modeling of the atmosphere with the hope of leading to improvements in the quantitative treatment of weather forecasting.

The VISSR selected for the SMS will be equipped with eight identical visible and two infrared sensors. The instantaneous geometric field of view at the subsatellite point for each visible sensor will be 0.25 by 0.021 milliradians (0.9-km earth resolution) and that of the infrared sensors will be 0.2 milliradians square (about 8-km earth resolution). The eight visible sensors will be aligned so that they scan the same total area as a single infrared sensor during each earth-viewing period. The second infrared sensor will be redundant and will view the same area as the primary sensor. The spin-scan image will be formed in the east-west plane by the spinning motion of the spacecraft while the north-south scan will be performed by mechanically tilting the scan mirror. The north-south scan will occur in discrete steps while the VISSR is looking into space. Thus, the image will be formed in very much the same way as a television picture. The total earth image will be composed of 1821 scans.

The wideband VISSR transmission from the spacecraft will be received at the Command and Data Acquisition Station (CDA) by synchronizing its transmissions with the spacecraft spin; the CDA will retransmit the VISSR data with a reduced bandwidth. This "stretched" VISSR data will be relayed through the SMS/GOES transponder to specialized ground stations.

The data collection system will enable environmental data sensed at more than 10,000 known-location Data Collection Platforms (DCP) to be relayed through the satellite to the CDA. Three methods of report initiation will be used; satellite interrogation, timed transmission, and threshold initiation. The platform utilizing threshold initiation will form an emergency network to give warning of the occurrence of earthquakes, tidal waves, river levels, and other potentially hazardous natural phenomena.

In addition, SMS/GOES will also have the capability to provide solar activity and space environment data which will be detected by energetic particle and magnetometer sensors. (A solar X-ray package will be considered a research and development instrument.)

(3) Research and Development Spacecraft

(a) Nimbus-5. Nimbus-5 was launched on December 11, 1972. It carried for the first time experiments sensing emission in the microwave part of the spectrum. Data from a single-channel ESMR have demonstrated the potential for mapping sea ice through clouds and delineating precipitating cloud systems over the world's oceans. Data from the Nimbus-5 Microwave Sounder have shown its ability to sound atmospheric temperature through overcast cloudiness, and it is already clear that the addition of microwave channels to infrared sounders of the future will markedly improve their accuracy and utility.

(b) Nimbus-F. Nimbus-F is scheduled to be launched in 1974 carrying the following eight meteorological experiments:

- THIR — Temperature Humidity Infrared Radiometer (two channels — 6.7 μm, resolution of ~ 24 km and 11 μm, resolution ~ 8 km).

- ESMR — Electrically Scanning Microwave Radiometer (one channel — 37 GHz, dual polarization, conical scan, resolution ~ 25 km).

- ERB — Earth Radiation Budget (measures solar constant and angular and spectral dependence of emitted and reflected radiation).

- SCAMS — Scanning Microwave Sounder (map tropospheric temperature profiles, water vapor abundance, and cloud water content).

- HIRS — High Resolution Infrared Sounder (17 channels, sounds temperature and water vapor, even in the presence of appreciable cloud cover).

- LRIR — Limb Radiance Inversion Radiometer (sounds temperature, water vapor, and ozone in the stratosphere for the first time using a limb scanning technique.)

- PMR — Pressure Modulated Radiometer (temperature measurements at altitudes between 45 km and 70 km on a global scale).

- TWERLE — Tropical Wind, Energy conversion, and Reference Level Experiment (collects data from and locates free-floating balloons and ocean buoys).

Nimbus-F will be a key element in support of the DST in 1974 and 1975. This activity is an important part of the GARP leading up to the FGGE in 1977 and 1978.

(c) Nimbus-G. Nimbus-G is a multidisciplinary satellite serving the application areas of pollution, oceanography, and weather and climate. These are three interrelated disciplines and the instruments are generally applicable to multiple disciplines. For example, a multichannel microwave radiometer is applicable to oceanography and meteorology, and a total ozone mapping sensor applies to both atmospheric pollution and weather and climate.

The weather and climate role for Nimbus-G is to obtain data about large scale atmospheric dynamics needed to support pollution and oceanographic investigations and to improve long range weather forecasting and our knowledge of processes affecting climatic change. The measurement of meteorological parameters over a time scale ranging from 12 hours to months or more is applicable to the monitoring and transport of pollutants as well as to increasing our knowledge of the structure, dynamics, and radiative and other energy exchange processes in the atmosphere and oceans. The ability to measure auxiliary parameters such as soil moisture, snow and ice cover, precipitation, and ozone and to more accurately measure sea surface temperature is needed for improved forecasts.

The Nimbus-G payload consists of the following instruments:

- Scanning Multichannel Microwave Radiometer (SMMR) — Measures radiances in four spectral bands with eight channels (because of dual polarization) in the wavelength region 0.8 to 2.8 cm to extract information on sea surface roughness and winds, cloud liquid water content, precipitation (mean droplet size), soil moisture, snow cover, and sea ice maps.

- Stratospheric and Mesospheric Sounder (SAMS) — Operates in a limb-scanning mode and employs pressure-modulated gas cells to obtain profiles of temperature and trace constituents in the region 15 to 100 km.

- Lower Atmosphere Composition and Temperature Experiment (LACATE) — Obtains in a limb-scanning mode profiles of temperature and trace constituents in the region 15 to 70 km.

- Solar-Backscattered Ultraviolet/Total Ozone Mapper System (SBUV/TOMS) — Measures direct and backscattered solar ultraviolet to extract information on variations of solar irradiance, vertical distribution of ozone, and total ozone on a global basis.

- Earth Radiation Budget (ERB) — Measures short and long wave upwelling radiances and fluxes and direct solar irradiance to extract information on the solar "constant," earth albedo, emitted long wave radiation, and the anisotropy of the outgoing radiation. This will continue the efforts to begin on Nimbus-F to measure the variability during the solar cycle.

- Measurement of Air Pollution from Satellites (MAPS) — Measures reflected and emitted radiances between 0.5 and 10.0 μm in seven spectral bands to extract information on global distribution of CO, SO_2, NO_2, CH_4, and NH_3 and of aerosols in the troposphere.

- Coastal Zone Color Scanner (CZCS) — Measures reflected solar radiances in six spectral bands between 0.443 and 0.950 μm and emitted terrestrial energy in the region 10.5 to 12.5 μm to extract information on chlorophyll concentrations in the oceans, sediment distribution, gelbstoffe (yellow substance) concentration as a salinity indicator, and temperature of coastal waters and ocean currents with an IFOV of 800 meters or less.

- Stratospheric Aerosol Measurements (SAM-II) — Measures the extinction of solar radiation at three wavelengths between 0.37 and 1.0 μm at spacecraft sunrise and sunset (viewing the solar disk through the limb of the atmosphere) to infer stratospheric aerosol properties.

(d) Other spacecraft of interest to weather and climate. Weather and climate instruments are sometimes flown on spacecraft with a prime mission in another discipline area. An example is the Geosynchronous Very High Resolution Radiometer (GVHRR) on the three-axis stabilized Applications Technology Satellites (ATS-F) to be launched in mid-1974 which will be capable of producing images with $\sim$ 5.5-km resolution the the visible and $\sim$ 11 km in the infrared. A full disk scan will require 24 minutes. There is also a sector mode in which the scan is restricted in the north/south plane to one-fourth of the earth's disk; this scan requires 6 minutes.

(4) Rockets. Another area in which NASA is involved in order to meet its obligations both nationally and internationally is that of meteorological sounding rockets. Meteorological rockets are a standard means of gathering in situ atmospheric data above the upper limit of the balloon-borne radiosonde (about 30 km). Much valuable information has become available from rocketsonde observations for use in a variety of research studies, as well as for the derivation of high altitude climatological and model atmospheres. There are three networks of concern to NASA: the Experimental Inter-American Meteorological Rocket Network (EXAMETNET), the U.S./U.S.S.R. Meteorological Sounding Rocket Agreement, and the Cooperative Meteorological Rocket Network (CMRN). The objectives of these networks is to increase man's knowledge of the upper atmosphere through an exchange of data, technical information, and scientific reports.

EXAMETNET is designed to provide synoptic information in the region from 30 to 60 km in both hemispheres. Initial operation of the network began in early 1966 with cooperative efforts between the U.S., Argentina, and Brazil. France, with a range in French Guiana, has joined EXAMETNET, and Spain has become and adjunct member. Japan, India, and several other countries have inquired about and are considering becoming adjunct members. An adjunct member is a country that does not have a range in the Americas.

In October 1971, a joint U.S./U.S.S.R. working group agreement between NASA and the U.S.S.R. Academy of Sciences was ratified. One of the projects within the agreement provided for coordinated meteorological sounding rocket launchings along two meridians (approximately 60 degrees east and 70 degrees west) to investigate the processes characterizing the physical state of the strato-mesospheric region of the atmosphere. To carry out this program, NASA is using the stations of EXAMETNET as well as those of the Cooperative Meteorological Rocket Network.

The CMRN, originally named the Meteorological Rocket Network, is a cooperative effort of NASA and the Department of Defense containing about 13 stations providing data covering the conditions in the upper atmosphere between 30 and 100 km.

Perhaps the most important function of the rocketsonde networks is providing an atmospheric temperature and wind field network for checking or comparing with the satellite temperature data obtained from the temperature profile radiometers, both infrared and microwave. The comparison studies include use of objective and subjective analyses of the data as well as comparisons of individual observed rocketsonde-radiosonde profiles with the satellite-derived profiles. They have been accomplished for various seasons including several stratospheric warming periods.

(5) Aircraft. The Earth Observations Aircraft play an important role in the development of remote sensing techniques as a companion to spacecraft and ground-based research. In the early period, the emphasis in the aircraft program was on the definition of sensor requirements and interpretive techniques. The aircraft currently are also used in an operating mode to provide observations at high and medium altitudes to complement and supplement spacecraft observations.

During 1974 the NASA Applications Aircraft will provide ocean color overflights, sea and lake ice monitoring, severe storm surveillance, pollution monitoring, and ground truth and calibration data for Nimbus-F, G, and SMS instruments. For example, a prototype Nimbus-G radiometer will be flown in 1974 on a U2 aircraft to provide truth data and to provide an early opportunity to apply and test new data processing techniques that will be used for Nimbus-G.

NASA will supply a vital link to the GARP Atlantic Tropical Experiment by providing the services of Galileo II, the replacement Convair 990 aircraft. This aircraft, a high altitude jet, is the only GATE-assigned aircraft capable of making measurements in the 10- to 12-km convective outflow region. It will be stationed in Dakar, Senegal to support GATE during the period June 15 through September 15, 1974.

An important extension of the aircraft program is the exploitation of commercial aircraft in a global monitoring system. Two flight systems are being built for 747 airline aircraft and one will be flown daily from New York to Hawaii starting in late CY-1974. The second system will be flown overseas on the Los Angeles-Australia-London route beginning in early CY-1975. Pollution data will be recorded 10 hours per day, 7 days per week by each plane. This will total approximately 6000 hours of pollution data per year gathered at very low operational cost.

d. Supporting Programs. To support these activities it is essential to plan and coordinate with those responsible for supporting operations and facilities. These include launch vehicles, testing of sensors and flight systems, data acquisition facilities and communication networks, spacecraft control operations, data pre-processing, and the operation of computing facilities used for information extraction and data analysis.

4. PROGRAM FUNDING

Figure III-3 and Table III-1 depict the Weather and Climate Program funding for FY-1968 through FY-1980. The program has been separated into five key elements as follows:

a. The research effort is planned to be held at the \$5 million level per year.

b. New initiatives in research proposed for start in FY-1976 include severe-storm-related research activities and the use of existing satellite sensor data for application in numerical models. These efforts will increase the research to approximately the \$10 million per year level.

c. The Operational Satellite Improvement Program has been increased to accommodate the additional satellite operational system; i.e., the GOES. The GARP will be funded at the \$7 to \$9 million per year level through FY-1978 to complete the effort for the FGGE.

d. The flight programs which peaked in FY-1973 at the \$51 million level include Nimbus-3, -4, -5, and -F; TIROS-M and -N; and SMS-A and B.

e. The new flight programs which are planned for launch in CY-1979 through CY-1982 include the Severe Storm Observing Satellite, the Radiation Budget Satellite, the Synchronous Earth Observatory Satellite TIROS-O (operational prototype), and the Zero-G Cloud Physics Laboratory for Spacelab. This effort will restore the total program to the \$60 million per year level after a noticeable decrease of about \$20 million per year in the level in FY-1975, -76, and -77. This gap was a result of the implementation of Nimbus-G as NASA's first major spaceflight effort in environmental quality in lieu of its originally planned weather and climate research role. Figure III-4 shows the schedule.

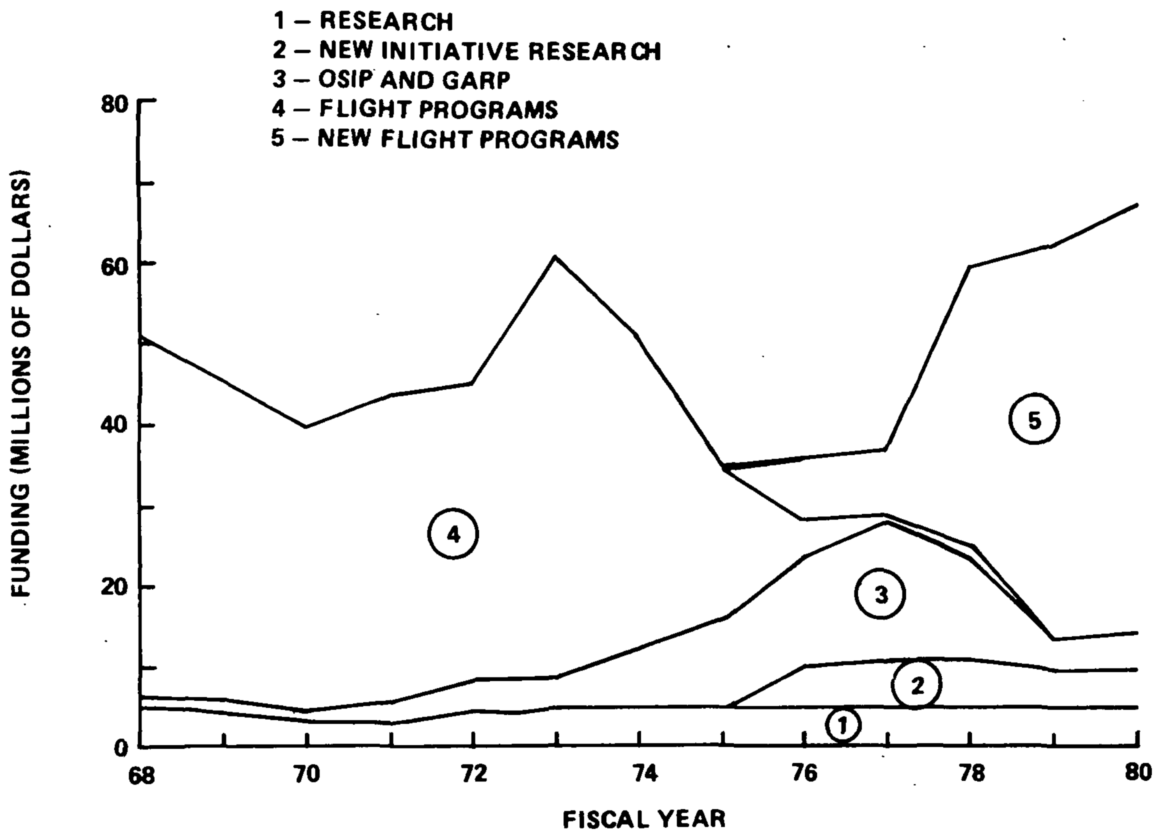

Figure III-3. Weather and Climate Program funding (millions of dollars versus fiscal year).

Average implementation costs for the Nimbus research satellite series 1 through F (seven missions) were approximately $50 million per mission not including launch vehicle costs. These average costs were composed as follows:

		Average Cost (Millions of Dollars) (Seven Missions)
Spacecraft		32.1
Sensors and Experiments		13.0
Ground Operations		3.5
	Total	48.6

TABLE III-1. WEATHER AND CLIMATE FUNDING HISTORY (MILLIONS OF DOLLARS)

	68	69	70	71	72	73	74	75	76	77	78	79	80
Research	5.2	4.8	2.7	2.7	4.6	4.4	5.0	5.0	5.0	5.0	5.0	5.0	5.0
New Initiative Research									5.5	6.0	6.0	4.5	4.5
OSIP	1.3	1.5	1.7	2.6	1.9	1.8	2.5	3.5	5.0	7.1	5.4	3.1	4.0
GARP				1.0	1.8	2.7	5.7	7.4	8.6	9.8	7.3		
Flight Programs	44.5	39.1	34.9	37.3	36.7	50.9	37.9	18.1	4.4	1.4	0.8		
New Flight Programs (For Planning Purposes)									7.7	7.4	34.2	49.5	53.6
Totals	51.0	45.4	39.3	43.6	45.0	59.8	51.1	34.0	36.2	36.7	58.7	62.1	67.1

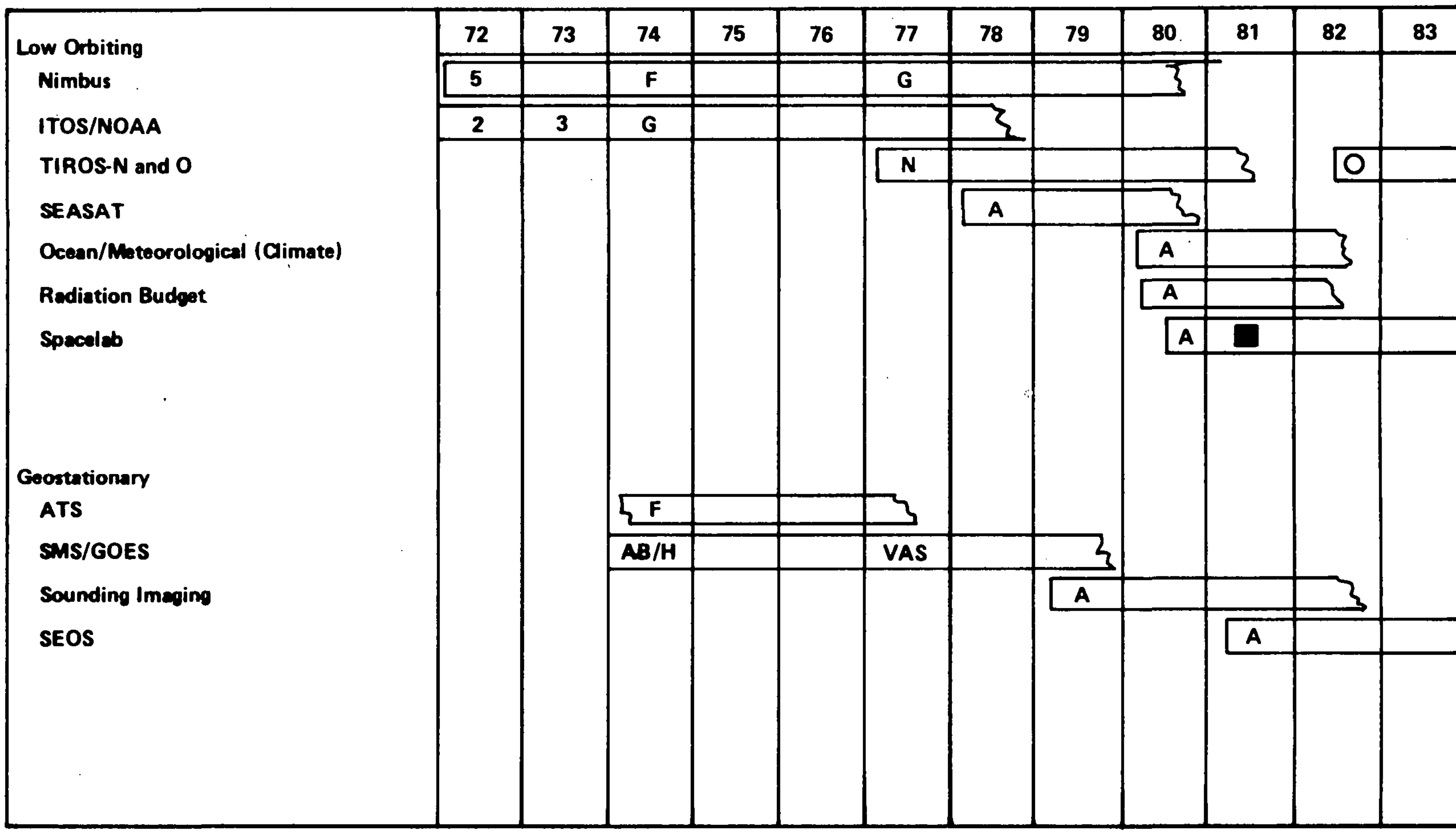

Figure III-4. Weather and Climate Program flight missions.

5. COST BENEFIT STUDIES

With the current and continuing emphasis on the need to justify Federal research activities in relation to the overall Federal budget and national priorities, questions are being asked, and will continue to be asked, about the ultimate value of the NASA programs.

While it is recognized that the NASA program in meteorology is primarily R&D and that the NOAA operational program furnishes the improvements in weather forecasting, NASA must be prepared to answer those questions related to the R&D costs of satellite meteorology.

Although numerous cost benefit studies have been conducted in the past and as a result several statements have been formulated by knowledgeable Federal organizations stating the weather related losses in dollars and cents, the much quoted figures are the total cost, with very little if any attention to the sensitivity of the relationship between loss reduction and forecast improvement.

There are two exceptions to the above statement. Both of these exceptions were the result of NASA contracts with (a) San Jose State College ("The Potential Economic Benefits of Improvements in Weather Forecasting," J. C. Thompson, Project Director) and (b) with the University of Wisconsin ("Multidisciplinary Studies of the Social, Economic, and Political Impact Resulting from Recent Advances in Satellite Meteorology," Verna Soumi, Project Director). These two studies are complementary to each other. The Wisconsion Report uses 11 case studies to illuminate three major areas of concern to the applied meteorology community. These are: (a) the agricultural sector, (b) the natural resources sector, and (c) the commercial activities sector. The individual case studies look at several diverse factors such as water resources management, the ski industry, the corn growing and canning industry, and the trucking industry.

The San Jose study, "The Potential Economic Benefits of Improvements in Weather Forecasting," describes an investigation of the future potential for economic gains associated with improvements in weather forecasting. The study was initiated as a consequence of the increased use of computers and other technological developments. Quoting Thompson — "That the emphasis in this study is on their economic and hence, monetary, value stems from the not inconsiderable costs associated with such devices, a circumstance which suggests the desirability of an assessment in like dimensions." Continuing,

Thompson says, "It should be noted, however, that neither the economic emphasis, nor the monetary results of the study, are intended to imply their sole use as criteria for making decisions concerning the intrinsic value of technological improvements in meteorology. On the contrary, economic gains should be considered only in context of the many benefits --- scientific, social, and others --- which have always been derived from the continuing search for fundamental knowledge of the atmospheric fluid in which man lives, and which constitutes a basic necessity for his existence." Thompson then proceeds to explain his meteorological economic model wherein he is able to show variations in potential economic gain with the length of the forecast period. For a dichotomous mini-max decision, there are three main variables influencing the potential gain: (a) scientific advances in the understanding of meteorology and forecasting, (b) operational improvements in the use of the basic forcasts, and (c) the length of the forecast period.

The Wisconsin report states that there are weather sensitive parameters for about 80 percent of the uses studies and there are substantial economic benefits to be obtained from increased weather information in the majority (70 percent) of the cases studied. Although it is impossible in this limited review to cover in any detail the results of the extensive agricultural case studies outlined in the five volumes of the Wisconsin report, it is possible to list a few of the highlights. The average annual loss from weather damage in corn farming was estimated to be $351 million (8 percent of total crop); loss in the wheat farming, $118 million (5 percent of total crop); and loss in the peanut crop, $38 million (10 percent of the total crop). The total average annual agricultural losses during the year 1951 through 1960 was more than $1 billion dollars per year.

Presently NASA-Goddard Space Flight Center has a study contract with ORI. The primary objective of this contract is to make a thorough literature search of all cost benefit studies completed since 1967. The contractor will then review and summarize the literature, identifying all significant data and information. The summary will contain a critique pointing out shortcomings and omissions as well as positive information.

In addition, the contractor will develop an outline plan or methodology for an in-depth study of selected potential benefit areas. The plan will outline the technical, economic, and social data flow trees required to develop a meaningful cost benefit analysis. The outline plan will consider all facets of the data flow from the spacecraft to the utlimate user.

The Wisconsion and ORI studies are further discussed in Chapter IX, "Economic Analysis."

6. INSTITUTIONAL ARRANGEMENTS

On July 2, 1973, a new agreement between DOC and NASA was signed superseding the 1964 agreement. A copy of this agreement, Basic Agreement Between U. S. Department of Commerce and the National Aeronautics and Space Administration Concerning Operational Environmental Satellite Systems of the Department of Commerce, is included in the Appendices volume. This new agreement makes the NOAA responsible for the management of the DOC functions set forth in the agreement. It expands the concepts of the old agreement to Operational Environmental Satellite Systems and is therefore not limited to meteorology. NASA has the responsibility for the development of supporting technology and for operational prototype spacecraft in support of the operational satellite system. NASA also has responsibility on a reimbursable basis for the procurement, launch, checkout, and tracking of operational satellites. Data from NASA research and development satellites will be made available to NOAA for operational use at the request of DOC-NOAA on a noninterference basis with added costs being reimbursable.

Another important element of the new agreement is the establishment of the DOC-NASA Satellite Program Review Board (SPRB). Section IV of the DOC-NASA July 2, 1973 agreement is as follows: "A DOC-NASA Satellite Program Review Board (SPRB) is hereby established. The Board is composed of two members each from NASA and DOC-NOAA, with the Associate Administrator for Applications of NASA and the Associate Administrator of NOAA serving as co-chairmen. The Board will meet quarterly or at the request of either co-chairmen to review the program and consider any substantive issues which may arise. It may make recommendations to the DOC and/or the NASA on the resolution of issues concerning the operational programs and their supporting R& D activity. Either chairman may refer any issue to the Deputy Administrator of NASA and to the Administrator of NOAA for resolution." Additional functions of the co-chairman of SPRB are specified in the DOC-NASA July 2, 1973, agreement Section V as follows:

"SECTION V. MEMORANDA OF UNDERSTANDING

A. A specific and separate memorandum of understanding, including reporting procedures, shall be negotiated and agreed for each major project. Examples of major projects are ITOS, TIROS N, SMS/GOES, etc. Memoranda will be co-signed by the co-chairmen of the Satellite Program Review Board established under the terms of Section IV above.

B. Memoranda of understanding for major projects shall include, as a minimum:

1. Commitment of NASA and NOAA staff to be assigned directly to the project for planning, technical, and administrative monitoring, including resident representation at contractor facilities.

2. Definition of authority

3. Reporting requirements

4. Schedule

5. Commitment of resources (funds, facilities, etc.)

C. Memoranda of understanding may be revised at the request of either co-chairman of the Satellite Program Review Board.

D. Supplementary memoranda of understand, within the terms of the above, may be negotiated at the working level as appropriate."

In addition to its agreement with DOC, NASA has an agreement with the Department of Defense (DOD) which provides for planning and coordination of activities and exchange of information. The Revised Agreement Between the Department of Defense and the National Aeronautics and Space Administration Concerning the Aeronautics and Astronautics Coordination Board, dated January 1971, is included in the Appendices volume.

The CMRN, originally named the Meteorological Rocket Network, is a cooperative effort of NASA and the Department of Defense containing about 13 stations providing data coverning the conditions in the upper atmosphere between 30 and 100 km.

The DOD is involved in NASA's effort to provide a prototype of the next generation polar orbiting operational meteorological satellite system. Thus the experience of the military weather program will also be utilized where economically beneficial.

In the area of meteorological sounding rockets, NASA is involved in several international agreements:

- The Experimental Inter-American Meteorological Rocket Network is designed to provide synoptic information in the region from 30 to 60 km in both hemispheres. Initial operation of the network began in early 1966 with cooperative efforts between the U.S., Argentia, and Brazil. France, with a range in French Guiana, has joined EXAMETNET, and Spain has become an adjunct member. Japan, India, and several other countries have inquired about and are considering becoming adjunct members. An adjunct member is a country that does not have a range in the Americas.

- A joint U.S./U.S.S.R. working group agreement between NASA and the U.S.S.R. Academy of Sciences was ratified in October 1971. One of the projects within the agreement provided for coordinated meteorological sounding rocket launchings along two meridians (approximately 60 degrees east and 70 degrees west) to investigate the processes characterizing the physical state of the strato-mesospheric region of the atmosphere.

NASA has been involved in the U.S. portion of the World Weather Program for many years and has been assigned key roles in the Global Atmospheric Research Program in addition to its vital role in the U.S. operational system which is a key element in the Global Observing System (GOS) of the World Weather Watch. The third major part of the World Weather Program is Systems Design and Technological Development; here NASA contributes in the areas of satellite balloon systems, research and development satellites, and supporting research and technology. NASA's contribution to the World Weather Program in FY-74 was $8 million direct and $51.7 million indirect out of a U.S. total of $23.7 million direct and $105.7 indirect. NASA's contribution is even greater if reimbursables are considered.

B. Earth Resources Survey

1. HISTORY

Remote sensing has been a technique long available to, and used by, many different agencies of the Government as well as a wide range of academic institutions and industrial concerns. Significant advances were made in the 1940's and 1950's as a result of military developments of airborne instrumentation for measuring terrestrial phenomena, for mapping and cartography, and for exploration of otherwise difficult-to-reach regions. With the advent of the space program, it was a logical extension of prior experience to seek to employ these same techniques in the higher altitudes of space. Even before the establishment of NASA, the Department of the Army was working on development of a satellite-borne infrared sensor system for weather observations. This satellite became the TIROS which, through the efforts of the Department of Commerce and NASA, has evolved into the current operational environmental satellite system of today. Cooperation between the Department of Commerce and NASA began in the late 1950's. In 1965, a formal interagency understanding was developed that defined the individual and joint responsibilities of the two agencies relative to the research, development, and operation of these satellite systems.

In the 1960's the manned flight projects (Mercury, Gemini, and Apollo) provided an opportunity for earth observations from space both with instruments and by the astronauts. The value of this very high altitude, large area coverage, observational capability soon became apparent to many institutions dealing in terrestrial and ocean phenomena. In 1964, together with NASA, the Department of the Navy established its Spacecraft Oceanography Project to investigate the potentials of remote sensing from space for oceanography and related disciplines. During this period, NASA requested a number of special interagency teams to investigate airborne and spaceborne remote sensing instrumentation and to assess its useful applications. The Corps of Engineers provided the first inter-Departmental look at the broad range of useful results that spaceborne instruments could provide for resource managers and scientists.

In 1966, the Department of the Interior, recognizing the eventual operational implications of space systems for earth resources survey, established its Earth Resources Observation System (EROS) Program and specifically requested NASA to begin the design and development of a satellite system for this purpose.

The interagency nature of the rapidly expanding Earth Resources Program, including both aircraft and manned and unmanned spacecraft elements, led to the establishment of more formally constituted coordinating mechanisms. In 1969, NASA requested the major user agencies — Agriculture, Navy, Commerce, Interior — to join in an interagency Earth Resources Survey Program Review Committee (ERSPRC) to analyze the total Earth Resources Survey (ERS) Program, to advise NASA on requirements, and to recommend user agency program integration. This mechanism became particularly important in establishing the rationale and research objectives for the experimental Earth Resources Technology Satellite. The Committee operated sucessfully within its limited scope until the spring of 1972, when the Interagency Coordination Committee for the Earth Resources Survey Program (ICCERSP) was chartered by the Office of Management and Budget. This Committee is the primary executive branch mechanism for coordinating all Federal earth resources activities.

At the request of NASA the National Academy of Science conducted a Summer Study on Space Applications in 1967. The following year the Academy's Central Review Committee reviewed the results, derived certain conclusions and recommendations, and published them in a report titled "Useful Applications of Earth Oriented Satellites." The following brief review of the recommendations with respect to earth resources in light of the events of subsequent years may be meaningful.

a. Scope of Funding

"NASA should give greater emphasis in its future programs and activities to earth-satellite programs with promise of beneficial applications.

Commit additional Federal funds to support, in certain applications, both an expanded research and development program and prototype operations that will test out the technical capabilities and benefit potentials of possible practical applications.

Provide $200 - 300 million a year to support the space-applications program at a level that is in the best interest of the United States."

Although the funding level has not approached that recommended, there has been the launching of the first Earth Resources Technology Satellite (ERTS-1) and the series of Skylab Earth Resources Experiment Package (EREP)

missions. Planning activities are also in progress for the second generation earth resources satellite (EOS-A), a synchronous earth resources satellite (SEOS-A), and Shuttle-era systems.

b. Research and Development Applications

"NASA should accept responsibility for organizing the required space-flight operational experiments in close cooperation with potential users, and for providing the necessary satellites and related ground equipments to execute this important phase in the development of space applications. Personnel from potential user agencies should be involved from the beginning in the planning and design of experimental programs."

An extensive and highly successful ERTS-1 investigative program has been organized and conducted. A cross section of the user community was represented as shown in Table III-2.

A similar investigative program involving a broad section of user participants was successfully conducted with the Skylab EREP missions.

Follow-on investigations employing ERTS-1 and ERTS-B data have been selected which also reflect a strong user involvement.

TABLE III-2. ERTS AND EREP DATA USE INVESTIGATIONS

	ERTS	EREP
Federal Agencies	66	41
State Agencies	16	10
Private	34	23
University	99	29
Foreign	105	41
Total	320	144

c. International

"NASA, in cooperation with the Department of State, should continue to develop its international programs concerned with space applications, even in the face of budgetary problems, to insure the development of a favorable climate for international acceptance and use of practical space applications, as they become technically feasible."

In addition to the 39 countries which participated in the ERTS and EREP programs, many other international cooperative efforts have been undertaken. NASA aircraft have collected remotely sensed data for Iceland, Argentina, Peru, Jamica, Puerto Rico, and Nicaragua. Remote sensing programs have been inititated in Mexico and Brazil with the encouragement and support of NASA. These two international cooperative programs included NASA aircraft missions in the respective countries as an aid to train their personnel. An international remote sensing workshop was conducted at Ann Arbor, Michigan, in 1970 under the sponsorship of several organizations including NASA. United Nation representatives were invited to an earth resources briefing at JSC in 1970 which was attended by over 20 nations. The International Affairs Subcommittee of the ICCERSP is actively seeking additional means to promote the peaceful utilization of space remote sensing.

d. Industry and Government

"Studies should be made to identify clearly the interests and possible responsibilities of the various user agencies with the ultimate objective of creating appropriate, viable, and effective organizations capable of adopting and managing the new systems."

This is a continuing effort with NASA working cooperatively with the many other user agencies to define the respective roles. The "Report of the Interagency Ad Hoc Study Group on the Earth Resources Survey Program" prepared under the auspices of the National Aeronautics and Space Council was but one of several comprehensive studies conducted. This study (referred to as the Ander's Report) was a key factor leading to the establishment of the ICCERSP. The reports and workings of the ICCERSP continue to better define and identify the organizations and systems needed in the future. Indeed, the 1974 Applications Summer Study should also serve to this end.

e. Earth Resources Satellites

1. "Support of sensor-signature R&D should be increased, as we are convinced that a modest investment in this area will generate great advances in our capability to evaluate the use of satellites for beneficial purposes.

We conclude that, in the near future, satellites can be flown with imaging sensors that can provide useful output data. A 200-foot resolution readout capability is initially useful for such a system. A common approach involving forestry, agriculture, geography, hydrology, and possibly oceanography is

feasible. Moreover, if a properly phased R&D effort could be started immediately, an operational system for overall earth resources information seems realizable within a decade, if the results of R&D are favorable."

A strong applications and technology program has been implemented. In addition to the broad scope of activities of the SR&T project, ERTS with its 60-80 meter resolution has supported approximately $20M of investigations.

2. "NASA should promptly initiate a pilot program to provide pictorial information in familiar and immediately useable form. This early system, which could be of the Global Land Use (GLU) type described in Panel Report No. 1 (Forestry-Agriculture-Geography), would furnish much of the understanding required for future, more advanced systems.

The potential value of side-looking radar for geology, which would contribute to this understanding, should be explored.

Planning (with appropriate check-points) should be started for evolution, within 10 to 12 years, of a substantially broader system with more sophisticated sensors. A facility of critical size is necessary to sustain the data processing and R&D needed to develop the second-generation system. Responsibility for the planning and coordination is an essential element, and should be assigned early. In this as in the early system, common elements among the disciplines should be stressed."

The continuing pictorial data supply from the ERTS series is the initial step in this program. Planning is in progress on the second generation system (EOS) within the suggested time frame. Side-looking radar applications for several disciplines in addition to geology are continuing to be investigated.

3. "We recommend that an early determination be made of operational and cost advantages realizable from the ongoing NASA Data Relay Satellite System program if, among other uses, the system replaces the NASA ground-tracking net. Pending the outcome, this program should continue with system definition and technology development."

The need for separate data relay satellite for future systems is being studied. In the meantime, the ERTS and its satellites have data collection platform relay capabilities which have proven very successful.

In summation, the recommendations of the 1967 Summer Study were welcomed, received strong consideration, and were appropriately implemented. They have had a significant influence on shaping the viable Earth Resources Program of today.

2. GOALS AND OBJECTIVES

The goal of the national program for earth resources is to investigate the application of remote sensing from air and space to improved surveying of earth resources and monitoring of the environment.

There are many environmental and resource applications which can benefit from the synoptic, repetitive, data gathering capability of remote sensing systems. Each of these specific applications may be characterized in terms of its spatial, spectral, and temporal data requirements. Meeting these requirements may require various mixes of spacecraft, aircraft, and ground data gathering capabilities. A principal function of the program is to determine these data requirements. The experimental flight missions will gather data for each potential application and determine the technical and economic feasibility of remote sensing data in operational applications.

These applications are broadly classified into six discipline areas:

- Agriculture, Forestry, and Range Resources
- Land Use Survey and Mapping
- Mineral Resources, Geologic Structure, and Landform Surveys
- Water Resources
- Marine Resources and Ocean Surveys
- Environmental Applications

a. Agriculture, Forestry, and Range Resources. Agriculture, forestry, and range applications are concerned with the planning of land use for food and fiber production and the management of those resources for the ultimate benefit of producers and users. Involved are the identification and monitoring of vegetation and associated soil and water parameters, and the detection and reduction of losses from disease, insects, weeds, droughts, floods, and fires.

The major goal within the agriculture, forestry, and range applications area is the efficient management of the Nation's renewable food and fiber resources. Accomplishment of this goal rests upon accurate and timely inventory and production estimates. Production estimates require knowledge not only of the types, amounts, and locations of the specific commodities of interest, but also information regarding the factors which influence the eventual quality and quantity of output. These factors include the physical condition of the plants themselves, i.e., vigor, density, damage, maturity, and environmental parameters such as the availability of water; soil type, porosity, salinity, and chemical constituents; and disease and insect infestations.

Objectives:

(1) Determine the requirements for, and assess the value of, space remote sensing applications for the individual subdisciplines (crop survey, forest survey, range survey, soil survey, and moisture survey).

(2) Develop and demonstrate the technological capability to perform useful areal inventories of major crop, timber, and range species and soil types.

(3) Develop and demonstrate the technological capability to accomplish useful production estimates for major crop, timber, and range species.

(4) Develop the technological capability and assess the value of performing direct operational services with remote sensing applications (e.g., stress control support, castastrophic event detection and recovery, and production operation).

b. Land Use Survey and Mapping Applications. Land use survey and mapping applications are concerned with the inventory of land use as an aid in planning for the most effective utilization of the land and other resources. It involves the production of land use and thematic maps and charts and statistical inventory information along with appropriate prediction modeling to provide information to a variety of users.

A useful immediate application of space remote sensing will be the production of detailed land use and thematic maps. Such information will be of use to all the applications areas for many Federal, state, and local agencies, private and public institutions, as well as the major user agencies. The degree of usefulness will be dependent upon the availability and timeliness of the information.

Objectives:

(1) Develop techniques for application of spacecraft data for large area, small scale land use mapping and inventory (Classification Level I and II).

(2) Develop techniques and applications for special purpose land use mapping and inventory at more detailed levels than Levels I and II using aircraft data and ultimately spacecraft.

(3) Develop mapping and cartographic techniques for space acquired data for:

- Quick turnaround and mass production of orthophotomaps.
- Producing theme maps and utilizing color coded information.

(4) Develop a land use information system retrieval system which permits user interaction.

c. Mineral Resources, Geologic Structure, and Landform Surveys. Mineral resources, geologic structure, and landform surveys are concerned with the exploration, inventory, and effective use of minerals, hydrocarbon fuels, geothermal resources and ground water; with investigating and understanding dynamic geologic phenomena, particularly those that pose a threat or hazard to human life or property; and with mapping and studying basic geologic features and processes.

Remote sensing may substantially increase the efficiency of exploration and inventorying of our mineral and energy resources such as iron, copper, mercury, petroleum, and natural gas by providing a method of quickly obtaining knowledge of geological relationships over large areas and identifying possible surface indicators of mineralization, such as surface staining or fracturing. These resources are critical to our modern industrial society, and because they are nonrenewable and are being used at increasing rates, developing better and more efficient methods of exploration is critical.

Objectives:

(1) Develop methods for improving the effectiveness of mineral, hydrocarbon, geothermal, and ground water exploration. Many mineral deposits are associated with either fracture or fault systems, topographic

anomalies, or color staining of surface rocks — all of which are at least partially distinguishable by remote sensing techniques. Geothermal sources, in many cases, emit detectable thermal energy that is distinguishable by remote sensing also.

(2) Develop methods for detecting, monitoring, and assessing dynamic geologic phenomena, particularly those of a destructive nature, with the goal of developing prediction techniques. These include:

- Volcanic zones
- Areas of earthquake activity
- Landslide prone areas
- Geologic factors related to mine cave-ins and roof-falls
- Erosion processes

(3) Apply remote sensing capabilities to mapping and studying major geologic features and processes (such as continental plate, tectonics, land-forming processes, etc.)

Remote sensing can help in identifying and assessing geological conditions causing hazardous events such as earthquakes and landslides. Millions of dollars in damages and hundreds of lives are lost annually by these and other destructive geological events. Finally, remote sensing can serve as a very useful tool in the study of geological structures, landforms, and rock types. Knowledge obtained from such studies contribute immeasurably to understanding basic geologic phenomena which cause deposition of minerals and various destructive events.

d. Water Resources. Water resources applications are concerned with managing the development, use, and conservation of water to assure availability for power generation, irrigation, flood control, navigation, industrial use, municipal water supply, and recreation. Included within the application area are flood prediction, monitoring, and control; locating underground sources; and identification and monitoring of degradation processes.

Fresh water is one of the Nation's most important assets. It is a renewable resource but must be wisely conserved if we are to have adequate supplies to meet the increasing demands. Sound management of water utilization is also necessary to avoid adversely affecting our environment and the ecological balance. To effect good management practices, a better understanding of hydrologic cycles and systems is necessary. The primary application of remote sensing to water resources is then to provide information for developing and improving hydrologic models. This includes the rapid determination of the significant factors and related measurements which lend themselves to remote sensing, development of the techniques to extract the necessary information, identification of specific signatures and their significant changes, and the testing and refinement of the hydrologic models. In addition to development of water management information systems, there are other significant applications of a more limited nature. Among these are the use of remote sensing for locating ground water discharge and underground sources; monitoring lake and river ice; monitoring lake, river, and reservoir water quality; assessing flood damage; and surveying the Nation's waterways for navigational hazards.

Objectives:

(1) Develop techniques to determine surface water chemistry and detect, measure, and map changes of salinity, eutrophication, and sedimentation.

(2) Develop river and lake ice identification, measurement, and mapping techniques and all weather monitoring capability.

(3) Develop watershed hydrologic models for estimating supply and distribution to be utilized for irrigation planning and scheduling, flood prediction, hydroelectric plant operations, river navigation management, and water supply scheduling.

(4) Develop methods to determine quantities of water entering an area such as determining precipitation volumes, measuring snow water content, and measuring snow melt rate.

(5) Develop watershed runoff and water movement models and techniques for measuring and mapping surface water characteristics and dynamics as well as other surface features relevant to these models.

(6) Develop techniques for mapping and supporting studies of glaciers, for detecting seepage from reservoirs, and for exploring for ground water sources.

e. Marine Resources. Marine resources are concerned with the physical (ice, temperature, currents, suspended sediment, and sea state), chemical (salinity and other chemical properties), biological (plants and animals), geometrical (ocean surface topography, land/sea interface, and bathymetry), and optical (water color and bottom color) features of the coastal and open zones of the oceans. The major goals within marine resources are:

(1) The efficient management of living marine resources.

(2) The efficient and effective management of activities within coastal zone regions.

(3) The effective use of the oceans and Great Lakes as transportation routes.

(4) The meaningful contribution to the basic sciences of marine biology, oceanography, and meteorology.

Objectives:

(1) Develop remote sensing methods and techniques for detection and inventory of living marine resources, and for determining biological/environmental relationships.

(2) Develop remote sensing techniques to monitor the polar regions (primarily the dynamic movement of the ice canopy in the Artic) to improve ice atlases through modeling techniques and thus improve accurate forecast of ice movement and conditions, and to improve the safety of transport in the Artic and Great Lakes.

(3) Develop techniques for measurement of dynamic and static ocean conditions in the coastal zones. Study of coastal processes entails certain aspects of both ocean color and dynamics, with many processes more accelerated than in the open ocean.

- Develop techniques for coastline delineation and change detection, wetland evaluations, shallow water bathymetry, general water circulation, including littoral and rip current analysis, bay and estuarine dynamics, upwelling phenomena, sediment transport, and algae blooms.

- Monitor and model estuary dynamics and ecological conditions using both remote and in situ measurements.

f. Environmental Applications. Environmental applications are concerned with the quality, protection, and improvement of land, water, and atmospheric resources insofar as they affect the health and welfare of human beings. For the ERS Program, the environment is limited to monitoring of wildlife migration, major biomes, fish and game areas, etc. The monitoring of air, water, and land pollution is considered in the Environmental Quality Program.

The major goal of the environmental applications area is to maintain the quality of the Nation's land and water resources. Accomplishment of this goal rests upon the collection and evaluation of physical, chemical, and biological data as they pertain to the earth's water and land resources. Evaluation of the data entails determining the conditions of the terrestrial environment and also requires the derviation of the standards that specify what they should be. Derivation of the standards requires an understanding of the interactions of various elements of the environment. The major elements impacting the environment include industrial activity; mining operations; agricultural, forestry, and range practices; wild and domesticated animal life; and man himself. These elements interact with each other and, in turn, with the Nation's land and water resources. Maintaining these interactions within a prescribed balance is the essence of the quality control function of the environmental discipline.

3. IMPLEMENTATION

Satisfaction of the ERS Program goals and objectives necessitates information regarding the various resources. The data, from which the information is to be extracted, will in general vary from one application to another with respect to resolution, frequency of coverage, spectral bands, and other parameters.

A broad variety of measurements and combinations of spacecraft, aircraft, and ground data will be necessary. The following three specific examples of data requirements will serve to indicate this diversity of needs:

a. Geologic exploration — The identification of large-scale geological features, using optical and reflective infrared imagery, may be accomplished with spatial resolutions in the 30- to 200-meter range. However, within geographical bounds suggested by the spacecraft imagery, subsequent stages of exploration may require much higher resolution, 15 to 30 meters for example, from aircraft followed by ground data collection.

b. Crop and forest inventory — Multistage sampling, based on optical and reflective infrared imagery, provides a promising approach to crop and forest inventory. Initial experiments indicate that large scale, relatively low resolution, spacecraft imagery (30 to 200 meters) can be combined with selected, higher resolution aircraft and ground data to provide improved estimates of timber volume. This techniques is applicable to a wide range of inventory problems where repetitive coverage at periods of days to months would be required.

c. Marine environment — Information on ocean temperature, sea state, and major current patterns, which are of great potential use to ocean navigation and the fishing industry, need only be obtained at spatial resolutions as gross as 1 to 10 km, but must be of high spectral resolution and must be updated more often than every 18 days. Present work empahsizes optical and infrared observations, but further extension into the microwave region could provide significant increments in capability.

Plans for achieving the program objectives should be based on the orderly and progressive development of the necessary systems and techniques. The NASA program is so oriented. Basic laboratory and field work, supported by aircraft-acquired data, in the 1960's led to the development of ERTS and its related investigations in the 1970's. The results of these investigations, augmented by the Skylab EREP experience, will lead to definition of the next generation space systems. This is the basic approach of the applications program. Basic research and development is conducted [primarily under the auspices of the Supporting Research and Technology Project (SR&T)] in which potential applications and system designs are studied. Those indicating most promise are selected for further development and verification testing via demonstrations. Multidiscipline flight programs complement system development efforts. Flight programs resulting from the R&D serve not only to test the system's concepts but provide a source of data for the R&D investigations.

Prior to initiating development of a new project, the plans are reviewed and approved. It should be noted that the following projects have been approved for planning only:

- Earth Observatory Satellite (EOS)
- Heat Capacity Mapping Mission (HCMM)

For the purposes of this description of the program, the projects are grouped into three types: (a) research and development, (b) complementary flight programs and demonstrations, and (c) flight programs. Figure III-5 indicates the breakout of activities by these types.

a. Research and Development Projects. There currently are four research and development projects: (1) Earth Resources SR&T, (2) Advanced Studies, (3) Shuttle Experiment Definition, and (4) EOS.

(1) Supporting Research and Technology. SR&T activities are directed toward developing sensors, data handling and processing systems, and interpretation techniques and exploring potential applications. The R&D program receives its direction from user requirements. While ERTS and Skylab data have demonstrated the feasibility of many applications, additional sensor capability is being developed and new requirements are being identified. Some new capabilities which need development include:

- Near real-time availability of data.

- Improved spatial, spectral, and temporal resolution. Increased spectral resolution, even at the expense of considerably degraded spatial resolution, together with increased data in the blue and green bands, is essential for oceanographic applications. More frequent coverage may be required for marine environmental monitoring.

- Improved onboard data processing and transmission capabilities to cope with the increased data rates expected from higher spatial and spectral resolution sensors.

- The capability for off-nadir pointing of sensors from satellite platforms would increase their flexibility and their effective repetition rates

- The use of active and passive microwave imagers for thematic mapping, soil moisture, and snowpack measurements. These microwave sensors may also be useful in defining the marine environment.

- The capability for continuous observation of short-time-constant phenomena on the earth's surface. This implies use of a geostationary spacecraft.

- Improved techniques for more accurate and rapid data processing and analysis.

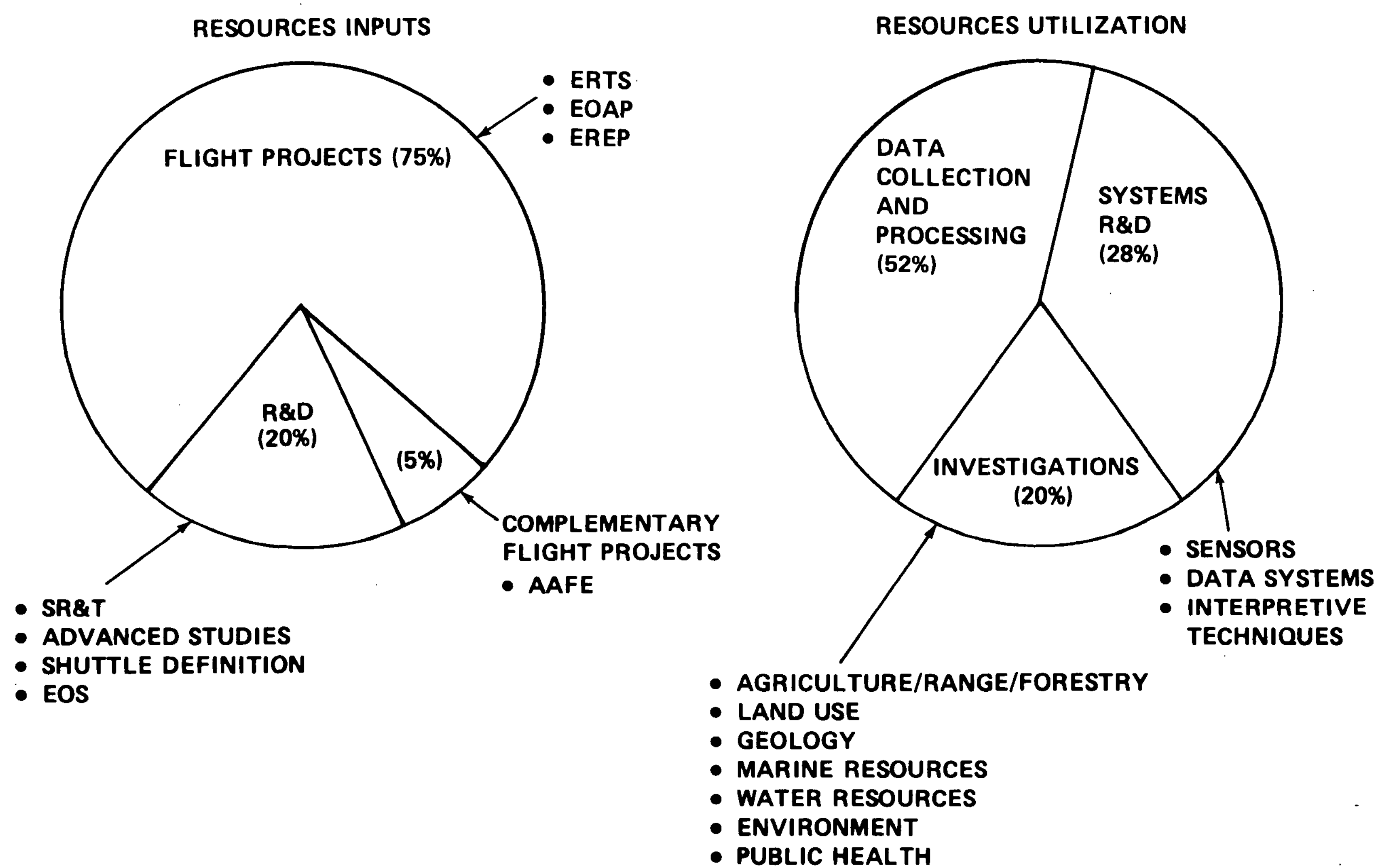

Figure III-5. Earth Resources Program activities (FY-74).

In addition to development of new and improved capabilities, exploratory investigations are conducted in all discipline areas to study, evaluate, and test potential applications. Universities and Centers of Excellence play a significant role in these basic research activities.

R&D sensor and systems development and exploratory investigations are usually conducted in conjunction with the flight programs. The majority of current activities are supported by the Earth Observations Aircraft Project.

A summary of the status of research activities in Earth Resources Survey is given in Figures III-6 through III-17.

(2) Advanced Studies. Planning for the future is of major significance. Rational decisions pertaining to courses of action must consider the options available. The purpose of conducting advanced studies is to enable NASA to analyze, evaluate, and study new and promising areas of applications responsive to various user needs, new concepts that fall within NASA's area of expertise, and alternate applications of systems and techniques.

Major studies underway include the following:

- An Earth Resources Survey Operational Systems Study aimed at defining an initial operational satellite system based on ERTS technology.

- Mission Requirements for a Synchronous Earth Observations Satellite (SEOS-A) which seeks to determine the requirements, characteristics, and operational parameters for a geosynchronous system which can increase opportunities for cloud-free viewing of some features and for monitoring short-lived, time-variant phenomena. Typical variable and transient phenomena include storms, flood, oil spills, forest fires, shortline erosion, and other hazards. SEOS will observe environmental phenomena, such as water color and temperature, which relate to food available in the oceans, and snowpack and surface water patterns, which relate to water supply management. Reflectivity studies of crops may locate areas stress-related to irrigation or infestation. The key element of SEOS will be a reflective telescope with a scanner adequate to achieve 0.2- to 1.5-km ground resolution in the 0.4- to 12.5-μm spectral range.

When the results of advanced studies indicate that more definitive effort is warranted for specific missions, new project starts are initiated. The Shuttle Experiment Definition and EOS projects are recent examples of this progressive development of system definition.

OBJECTIVES*	CURRENT STATUS USING ERTS DATA	POTENTIAL ASVT'S
CROP SURVEY ● IDENTIFICATION ● AREAL INVENTORY ● YIELD ASSESSMENT ● PRODUCTION ESTIMATES	● FEASIBILITY DEMONSTRATED FOR SELECTED CROPS AND TEST AREAS. 90% IDENTIFICATION ACCURACY FOR FIELDS GREATER THAN 20 ACRES ● FIELD MENSURATION OF CROPS IS FEASIBLE BUT LIMITED BY A NUMBER OF FACTORS. 70-90% ACCURACY. ● NO PRODUCTION ASSOCIATED RESULTS USING ERTS DATA WITH ADP INTERPRETATION	ERTS ● LARGE AREA CROP INVENTORY FUTURE ● U.S. MAJOR CROP INVENTORY
FOREST SURVEY ● IDENTIFICATION ● AREAL INVENTORY ● PRODUCTION ESTIMATES	● FEASIBILITY DEMONSTRATED FOR SELECTED TEST AREAS AND BROAD RESOURCES TYPES OF 70-80% IDENTIFICATION ACCURACY ● GOOD CONTACT WITH THE USER COMMUNITY ● TIMBER VOLUME MEASUREMENT MET DISTRICT LEVEL USFS NEEDS ● MANY EXAMPLES OF COST/BENEFITS EVEN WITH GROSS ANALYSES ● BURN SCARS IDENTIFIED BASED ON SECONDARY-SUCCESSION TEXTURAL CHANGES	ERTS ● LIMITED INVENTORY OF SELECTED U.S. FORESTS FUTURE ● U.S. FOREST INVENTORY UTILIZING EOS CLASS DATA
RANGE SURVEY ● IDENTIFICATION ● STRATIFICATION ● PRODUCTION ESTIMATES	● FEASIBILITY DEMONSTRATED FOR GROSS SURVEYS AND CHANGE DETECTION/MONITORING IN SELECTED AREAS ● CAPABILITY TO PROVIDE DETAILED INFORMATION MAY BE LACKING ● MANY RANGE IDENTIFICATIONS PERFORMED BY ASSOCIATION WITH OTHER NATURAL CHARACTERISTICS ● QUALITATIVE INTERPRETATION USEFUL TO BLM	ERTS ● RANGE READINESS AND FORAGE FOR GRAZING MANAGEMENT FUTURE ● TBD
SOIL SURVEY ● IDENTIFICATION	● FEASIBILITY DEMONSTRATED FOR DELINEATING SOIL ASSOCIATIONS IN SELECTED AREAS	ERTS ● SOIL ASSOCIATION MAPPING IN NEW AREAS AND VERIFICATION OF EXISTING MAPS FUTURE ● TBD
MOISTURE SURVEY	● FEASIBILITY DEMONSTRATED TO DELINEATE LARGE AND RELATIVE DIFFERENCES IN AVAILABLE SOIL MOISTURE ● QUANTITATIVE MEASUREMENTS APPEAR TO REQUIRE SENSORS NOT ON ERTS-1 ● QUALITATIVE SURVEY OF REGIONAL MOISTURE AFFECTING VEGETATION PERFORMED WITH CHANGE DETECTION ON WATER IMPOUNDMENTS (PLAYAS, RIVERS, LAKES, AND RESERVOIRS.)	FUTURE ● TBD

*IN ORDER OF PRIORITY

Figure III-6. Agriculture/forestry/range.

RESEARCH AND TECHNOLOGY AREAS	PLANNED OR UNDERWAY	NEEDED
GENERAL • IMPROVED SPECTRAL AND SPATIAL RESOLUTION IDENTIFICATION • IMPROVED IDENTIFICATION ACCURACY WITH TEMPORAL ANALYSES, CROP CALENDAR, AND EXTENSION OF TECHNIQUES BETWEEN AREAS. STRESS IDENTIFICATION AND SEVERITY DETERMINATION STUDY RATIO TECHNIQUES. AREAL INVENTORY • IMPROVED AREA MEASUREMENT CONSIDERING FIELD BOUNDARIES, MINIMUM SIZE, AND SHAPE. DEVELOPMENT AND IMPROVEMENT OF SAMPLING APPROACHES YIELD ASSESSMENT • MODELS OF FACTORS AFFECTING YIELD PRODUCTION ESTIMATION • SAMPLING STRATEGIES AND INTEGRATION OF ABOVE	GENERAL • IMPROVED SPECTRAL AND SPATIAL RESOLUTION IN EOS. ESTABLISHMENT OF STATISTICAL EXPERIENCE BASE IN PROGRESS. IDENTIFICATION • IMPROVED IDENTIFICATION ACCURACY AND STATISTICAL VALIDITY. EXTENSION OF TECHNIQUES BETWEEN AREAS. RATIO TECH IN STUDY. AREAL INVENTORY • IMPROVED AREA MEASUREMENT CONSIDERING FIELD BOUNDARIES, MINIMUM SIZE, AND SHAPE YIELD ASSESSMENT • MINOR SRT ON FACTORS AFFECTING YIELD	GENERAL • USE OF A/C FOR RESEARCH UNTIL IMPROVED SPACE CAPABILITY AVAILABLE IDENTIFICATION • INCREASED IDENTIFICATION CAPABILITY WITH TEMPORAL ANALYSES AND CROP CALENDARS. RESEARCH ON STRESS IDENTIFICATION AND SEVERITY DETERMINATION. AREAL INVENTORY • DEVELOPMENT AND IMPROVEMENT OF SAMPLING APPROACHES YIELD ASSESSMENT • DEVELOPMENT OF YIELD ASSESSMENT MODELS PRODUCTION ESTIMATION • SAMPLING STRATEGIES AND INTEGRATION OF IDENTIFICATION, AREAL AND YIELD WORK
GENERAL • IMPROVED SPATIAL RESOLUTION IDENTIFICATION • TECHNIQUES TO OVERCOME NON-HOMOGENEOUS PATTERN OF TIMBER. PREVISUAL STRESS IDENTIFICATION. EXTENSION OF TECHNIQUES BETWEEN FOREST REGIONS. IMPROVED ACCURACY IN IDENTIFICATION OF STRESS DAMAGE AND SEVERITY. EMPHASIS ON COMPUTER ANALYSIS. AREAL INVENTORY • COMPREHENSIVE EVALUATION OF MULTI-STAGE SAMPLING. IMPROVED ACCURACIES.	IDENTIFICATION • EXTENSION OF TECHNIQUES BETWEEN FOREST REGIONS. IMPROVED ACCURACY IN IDENTIFICATION OF STRESS DAMAGE. AREAL INVENTORY • IMPROVED ACCURACIES PRODUCTION ESTIMATION • RESEARCH ON DETECTABLE FACTORS RELATING TO PRODUCTION (VOLUME) OF TIMBER. ESTABLISHMENT OF STATISTICAL EXPERIENCE BASE IN PROGRESS.	GENERAL • IMPROVED SPATIAL RESOLUTION. USE OF A/C FOR RESEARCH UNTIL IMPROVED SPACE SENSOR CAPABILITY IS AVAILABLE. IDENTIFICATION • DEVELOPMENT OF TECHNIQUES TO OVERCOME NON-HOMOGENEOUS PATTERN OF TIMBER. RESEARCH ON PREVISUAL STRESS IDENTIFICATION. AREAL INVENTORY • MORE COMPREHENSIVE EVALUATION AND DEVELOPMENT OF MULTISTAGE SAMPLING. TECHNIQUES FOR HANDLING LARGE VOLUMES OF DATA.
IDENTIFICATION • DETERMINE ACCURACY REQUIREMENTS. EVALUATE USEFULNESS OF PHENOLOGICAL PROGRESSION MONITORING. INCREASE USE OF COMPUTER ANALYSIS. PRODUCTION ESTIMATION • ESTABLISH QUALITATIVE ESTIMATES FOR RANGE FORAGE PRODUCTION. STUDY RATIO TECHNIQUES.	STRATIFICATION • MINOR ERTS PHOTOINTERPRETIVE INVESTIGATIONS PRODUCTION ESTIMATION • RATIO TECHNIQUES IN STUDY. FORAGE QUANTITY RELATED TO REFLECTANCE.	GENERAL • COMPLETE FEASIBILITY AND COST/BENEFIT ANALYSES IDENTIFICATION • DETERMINE ACCURACY REQUIREMENTS. EVALUATE USEFULNESS OF PHENOLOGICAL PROGRESSION MONITORING. PRODUCTION ESTIMATION • INCREASED EFFORT TO ESTABLISH QUANTITATIVE ESTIMATES FOR RANGE FORAGE PRODUCTION
GENERAL • CONDUCT COST/BENEFITS ANALYSES. DEVELOP USE OF COMPUTER ANALYSIS. IDENTIFICATION • IMPROVED IDENTIFICATION ACCURACY. EXTEND TECHNIQUES TO MANY DIFFERENT REGIONS.	IDENTIFICATION • IMPROVED IDENTIFICATION ACCURACY AND STATISTICAL VALIDITY	GENERAL • CONDUCT COST/BENEFITS ANALYSES IDENTIFICATION • EXTEND TECHNIQUES TO MANY DIFFERENT REGIONS
GENERAL • EVALUATE THERMAL AND MICROWAVE MEASUREMENT USEFULNESS. CONSIDER USE OF SATELLITE METEOROLOGICAL DATA IN ESTIMATING PROBABLE RAINFALL.	GENERAL • MINOR WORK IN PASSIVE MICROWAVE AREA. PLANNED L-BAND RADAR SURVEY OF WATER PONDS BY KSC. USE OF X-L BAND RADAR BY JSC.	GENERAL • COORDINATED PLAN FOR SOIL MOISTURE SURVEY CAPABILITY DEVELOPMENT

Figure III-7. Agriculture/forestry/range.

OBJECTIVES*	CURRENT STATUS USING ERTS DATA	POTENTIAL ASVT'S
LAND USE INVENTORY • BROAD CLASSIFICATION (LEVELS I & II) • DETAILED CLASSIFICATION (LEVELS III & IV)	IMAGE INTERPRETATION TECHNIQUES • CLASSIFICATION BEYOND THE NINE LEVEL I CATEGORIES • BETTER FOR BROAD AREA CALSSIFICATION (LEVELS I & II, EXCEPT URBAN) AUTOMATIC DATA PROCESSING TECHNIQUES (PATTERN RECOGNITION) • LARGER NUMBER OF CATEGORIES CAN BE DETERMINED THAN WITH IMAGE INTERPRETATION • MANY LEVEL II CATEGORIES OUTSIDE URBAN AREAS DETERMINED • ADP BETTER FOR DETAILED CLASSIFICATIONS (LEVELS I, III, & IV) • SOME LEVEL III • SOME URBAN (LEVELS II & III) APPLICATIONS • REGIONAL & RURAL - NEAR OPERATIONAL • URBAN - NOT COMPATIBLE FOR DETAILED APPLICATIONS. ONLY GROSS CHANGE DETECTION IS MONITORING FOR PLANNING & OVERVIEW	ERTS • STATEWIDE (MISSISSIPPI) LAND USE DEMONSTRATION • REGIONAL (TEXAS) LAND RESOURCES INVENTORY • LARGE AREA (NATIONAL/INTERNATIONAL) RESOURCES INVENTORY FUTURE • NATIONAL LAND USE INVENTORY WITH EOS
MAPPING AND CARTOGRAPHY • MAP COMPILATION • PHOTO MAPPING • MAP REVISION • CONTROL • THEMATIC MAPS	MAP COMPILATION • NOT SUITABLE FOR PREPARING NEW MAPS AT SCALES LARGER THAN 1:500,000 PHOTOMAPPING • SUITABLE FOR 1:500,000 PHOTOMAPS SUITABLE FOR 1:250,000 WITH DIGITAL CORRECTIONS MAP REVISION • COMPLEMENT EXISTING LINE MAPS AT SCALES 1:250,000 AND LARGER • SUPPORT REVISION OF EXISTING LINE MAPS AT A LARGE VARIETY OF SCALES CONTROL • ERTS CAN BE USED FOR GENERATING CONTROL (HORIZONTAL) WHERE SOME CONTROL IS ALREADY AVAILABLE THEMATIC MAPS • LARGE AMOUNTS OF THEMATIC INFO CAN BE EXTRACTED BY VISUAL OR ADP TECHNIQUES	ERTS • STATEWIDE (MISSISSIPPI) LAND USE DEMONSTRATION • REGIONAL (TEXAS) LAND RESOURCES INVENTORY • LARGE AREA (NATIONAL/INTERNATIONAL) RESOURCES INVENTORY FUTURE • NATIONAL AND WORLD-WIDE MAPPING USING EOS
LAND USE INFORMATION MANAGEMENT AND MODELING		ERTS • REGIONAL LAND RESOURCES INVENTORY SYSTEM

*IN ORDER OF PRIORITY

Figure III-8. Land use surveys.

RESEARCH AND TECHNOLOGY AREAS	PLANNED OR UNDERWAY	NEEDED
• AUTOMATIC (PATTERN RECOGNITION) TECHNIQUES • CLASSIFICATION TECHNIQUES APPLICABLE TO A WIDE RANGE OF CONDITIONS • TECHNIQUES TO MINIMIZE THE NEED FOR GROUND AND AIRCRAFT DATA • TECHNIQUES TO QUANTIFY ACCURACY AND PRECISION OF CLASSIFICATION • TECHNIQUES FOR INTEGRATION OF TEMPORAL DATA AND DIFFERENT SENSORS FOR REFINED CLASSIFICATION • TECHNIQUES TO REMOVE SCAN/SUN ANGLE EFFECTS FROM AIRCRAFT DATA FOR CLASSIFICATION • SPATIAL PATTERN RECOGNITION TECHNIQUES • UTILITY OF MICROWAVE AND THERMAL IR DATA	• SIMPLIFYING AND STREAMLINING PRODUCTION SOFTWARE FOR SUPERVISED AND UNSUPERVISED TECHNIQUES • DETERMINATION AND CORRELATION OF GEOMETRIC DISTORTION • DEVISING CLASSIFICATION TECHNIQUE ADAPTABLE TO TEMPORAL EFFECTS • DEVISING SAMPLING TECHNIQUES IN AREAS IDENTIFIED AS DIFFERENT IN UNTRAINED CLASSIFICATIONS • DEVELOP AND APPLY ATMOSPHERIC RADIOMETRIC CORRECTIONS • DEVELOP & APPLY RADIOMATRIC CORRECTIONS TO MULTISPECTRAL DATA • ANALYZE LAND USE CLASSIFICATION TO ESTABLISH FINAL ACCURACY NEEDS • ESTABLISHING ACCURATELY THE BOUNDARIES OF SPECIFIC LAND USE AREAS • ESTABLISHING ACCURACY WITH WHICH INFORMATION CAN BE ASSOCIATED TO A GEOGRAPHIC GRID SYSTEM • IDENTIFICATION OF FEATURES, MEASUREMENT OF AREA, AND MANUALLY REGISTERED WHEN INTEGRATING SENSOR SOURCES AND TEMPORAL DATA • DERIVING AND TESTING SOFTWARE THAT USES THE SPATIAL STRUCTURE TO AID CLASSIFICATION AND ANALYSIS	• ADAPT & MODIFY SOFTWARE FOR GENERAL PURPOSE COMPUTERS • DEVELOP AN AUTOMATED CLASSIFICATION TECHNIQUE USING INTEGRATED SENSOR SOURCES AND TEMPORAL DATA • DEVELOP AUTOMATED CHANGE DETECTION TECHNIQUES • DEFINE THEORETICAL AND PRACTICAL UTILITY OF MICROWAVE AND THERMAL IR DATA FOR LAND USE APPLICATIONS
• TECHNIQUES TO ACHIEVE GEOMETRIC CORRECTIONS USING DIGITAL TECHNIQUES • MAPPING IN REMOTE AREAS • UTILITY OF EREP-LEVEL PERFORMANCE SYSTEM FOR WORLD-WIDE USE • TECHNIQUES FOR QUICK TURNAROUND, MASS PRODUCTION OF CARTOGRAPHIC AND THEMATIC MAP PRODUCTS	• DEVELOPING TECHNIQUES BY GSFC AND JSC TO ACHIEVE GEOMETRIC CORRECTIONS WHILE STILL PRESERVING RESOLUTIONS • DEVELOPING & EVALUATING TECHNIQUES USING CONVERGENT PHOTOGRAPHY TO PERMIT MAPPING INDEPENDENTLY OF GROUND CONTROL	• EVALUATE THE VALUE OF EREP-LEVEL SYSTEM FOR WORLD-WIDE USE
• DEVELOP & IMPROVE INFORMATION STORAGE AND RETRIEVAL TECHNIQUES • DEVELOP MANIPULATION REQUIRED TO UTILIZE LAND USE AND NATURAL RESOURCE INFORMATION • INTEGRATION OF INFORMATION MANAGEMENT SYSTEMS WITH THE AUTOMATIC CLASSIFICATION SYSTEMS TO PROVIDE A MEANS FOR UPDATING THE DATA BASE AND TO PROVIDE PRIORITY CLASSIFICATION PROBABILITIES • MODELING DEVELOPMENT	• VARIOUS AND NUMEROUS OUTPUT PRODUCTS HAVE BEEN DERIVED. STANDARDIZATION AND MINIMIZING THE NUMBER OF PRODUCTS IS UNDERWAY • JSC RIMS/HATS SRT PROJECT	• DEFINITION & DEVELOPMENT OF MANIPULATION TECHNIQUES FOR REGIONAL LAND RESOURCES INVENTORY SYSTEM • DEFINITION & DEVELOPMENT OF INTEGRATION FOR REGIONAL LAND RESOURCES INVENTORY SYSTEM • PURSUE UTILIZATION OF OPERATIONAL MODELING (i.e., URBAN)

Figure III-9. Land use surveys.

OBJECTIVES*	CURRENT STATUS USING ERTS DATA	POTENTIAL ASVT'S

RESOURCES EXPLORATION
• MINERAL RESOURCES
  • METAL ORES
  • BUILDING STONE, AGGREGATE
• HYDROCARBON RESOURCES
  • PETROLEUM EXPLORATION
  • COAL EXPLORATION
• GEOTHERMAL RESOURCES
• GROUND WATER RESERVES
	• LINEAMENT INTERSECTIONS CORRELATED TO KNOWN DEPOSITS. SOME NEWLY FOUND STRUCTURES HOLD PROMISE OF NEW DEPOSITS-AWAIT GROUND EXPLORATION FOR CONFIRMATION
	• KNOWN OIL-BEARING STRUCTURES IN CAL. CORRELATED WITH NEWLY DISCOVERED LINEAMENTS. SURFACE EXPRESSIONS OF SALT DOMES NOTED IN GULF COAST REGION. ANOMALOUS FEATURE IDENTIFIED IN ALASKA COULD CONTAIN OIL-BEARING SEDIMENTS-GROUND EXPLORATION NEEDED FOR CONFIRMATION
	• INDIRECT INDICATIONS OF GEOTHERMAL ACTIVITY NOTED BY MAPPING OF SNOW COVER OF FEW SELECTED VOLCANOS
	• SUCCESSFUL WELL DRILLED IN LOCAL PERCHED AGUIFER IDENTIFIED IN ERTS; FRACTURES CORRELATED TO SPRINGS
		ERTS
		• METAL ORE EXPLORATION
		• OIL EXPLORATION
		FUTURE
		• IMPROVED METAL ORE EXPLORATION
		• IMPROVED OIL EXPLORATION
		• GEOTHERMAL RECONNAISSANCE SURVEY

HAZARDS & CIVIL WORKS ASSESSMENT
• VOLCANO SURVEYS
• EARTHQUAKE SURVEYS
• LANDSLIDE ZONE SURVEYS
• MINE SAFETY SURVEYS
• CIVIL WORKS
• EROSION SURVEYS
  • WATER EROSION
  • WIND EROSION
	• USGS DCS SYSTEMS SUCCESSFULLY MONITORING VOLCANIC ACTIVITY ON SELECTED VOLCANOS, HAVE DEMONSTRATED ERUPTION PREDICTION CAPABILITIES ON VOLCANO IN GUATAMALA
	• NEW FAULTS OR EXTENSIONS OF KNOWN ONES EXTENSIVELY FOUND, SIGNIFICANT EARTHQUAKE EPICENTERS CORRELATE TO LOCATIONS OF SOME
	• SOME CORRELATION BETWEEN IMAGE-DETECTED FRACTURES AND MINE CAVEINS FOUND IN COAL MINING DISTRICT OF INDIANA. HAZARDOUS PERMAFROST SUSCEPTIBLE AREAS IDENTIFIED.
	• HAZARDOUS PERMAFROST SUSCEPTIBLE AREAS IDENTIFIED
	• LARGER ARROYOS IN S. ARIZONA DETECTED & MAPPED. AREAS OF SEVERE SAND & GRAVEL DEPOSITION CAUSED BY FLOODS DETECTED. STREAM SEDIMENTS DETECTED.
		ERTS
		• IDENTIFICATION OF EARTHQUAKE PRONE AREAS
		• IDENTIFICATION OF HAZARDOUS ZONES PRONE TO ROOF-FALLS IN MINES
		FUTURE
		• VOLCANO ERUPTION PREDICTION
		• LANDSLIDE-PRONE AREAS MONITORING, LANDSLIDE PREDICTION
		• STUDY OF ERODED AREAS OVER LONGER TERM (SEVERAL YEARS) PERIOD

GEOLOGIC FEATURES & PROCESSES • STRUCTURAL SURVEYS • GEOMORPHOLOGIC (LANDFORM) SURVEYS • LITHOLOGIC (ROCK-TYPE) SURVEYS	• FRACTURES, FAULTS, FOLDS, INTRUSIVES, AND IMPACT STRUCTURES DETECTED WITH VARYING SUCCESS, DEPENDENT ON SIZE, STRUCTURAL SETTING, CONTRAST, EXTENT OF GROUND COVER, SUN ANGLE, ETC. DETECTION OF REGIONAL LINEAMENTS BIGGEST PAYOFF TO GEOLOGY FOR ERTS. • MOST HIGHER-ORDER GEOMORPHIC UNITS (MOUNTAINS, BASINS, LAKES, GLACIAL FEATURES, SAND DUNE FIELDS, VOLCANIC FEATURES, OCEANS, COASTAL FEATURES, ETC.) WELL DISPLAYED - REGIONAL VIEW HIGHLY SIGNIFICANT. • FEW RELIABLE IDENTIFICATIONS OF ROCK TYPES MADE DUE TO RESOLUTION LIMITS (MOST STRATIGRAPHIC UNITS THINNER THAN SPATIAL RESOLUTION LIMITS) AND "NON-UNIQUENESS" OF SPECTRAL SIGNATURES FOR INDIVIDUAL ROCK TYPES	ERTS • TBD FUTURE • AUTOMATED SURFACE GEOLOGICAL MAPPING

*IN ORDER OF PRIORITY

Figure III-10. Mineral resources, geologic structure, and landform surveys.

RESEARCH TECHNOLOGY AREAS	PLANNED OR UNDERWAY	NEEDED
• IMAGE ENHANCEMENT TECHNIQUES - TO ENHANCE STRUCTURAL FEATURES & SURFACE ALTERATION ZONES ASSOCIATED WITH MINERALIZED AREAS, AREAS OF PETROLEUM CONCENTRATIONS, GROUND WATER ZONES, FEATURES IMPORTANT IN CAUSING LANDSLIDES & EROSION, AND IN IDENTIFYING STRUCTURES, LANDFORMS, AND ROCK-TYPES • MULTISPECTRAL IMAGING FEATURE IDENTIFICATION (NEAR IR & THERMAL CHANNELS) - TO UNDERSTAND THE GEOLOGICAL INFORMATION CONTENT AND EVALUATE THE USEFULNESS OF THE "NON-VISIBLE" MSS CHANNELS FOR GEOLOGICAL APPLICATIONS	• JPL, IMAGE PROCESSING LAB - DIGITAL METHODS FOR ENHANCING GEOLOGICAL FEATURES • VARIOUS ERTS & EREP INVESTIGATORS - USING OPTICAL (COLOR-ADDITIVE VIEWING, DIAZO-CHROME METHODS) AND SOME DIGITAL METHODS (DENSITY SLICING, BAND RATIOING, LEVEL STRETCHING) • ERIM - RESEARCH IN RADIOMETER FEATURE DISCRIMINATION • VARIOUS ERTS & EREP INVESTIGATORS - USING ERTS 4-CHANNEL MSS AND EREP 13-CHANNEL MSS IMAGERY TO INVESTIGATE DISCRIMINATION OF FEATURES	• IMPROVED DIGITAL ENHANCEMENT TECHNIQUES & IDENTIFICATION OF OPTIMUM BANDS & RATIOS FOR ENHANCING VARIOUS FEATURES SUCH AS SURFACE STAINING, "TONAL ANOMALIES," ROCK TYPES ASSOCIATED WITH MINERALIZATION • EVALUATION OF USEFULNESS OF SPATIAL FILTERING TECHNIQUES TO ENHANCE LINEAR STRUCTURES • EVALUATION OF GEOLOGICAL INFORMATION CONTENT CONTAINED IN "NON-VISIBLE" MSS CHANNELS
• ACTIVE MW IMAGING FEATURE IDENTIFICATION - TO UNDERSTAND THE GEOLOGICAL INFORMATION CONTENT AND EVALUATE THE USEFULNESS OF ACTIVE MW IMAGERY FOR GEOLOGICAL APPLICATIONS • AUTOMATED COMPUTER RECOGNITION/CLASSIFICATION OF TERRAIN - TO IDENTIFY ROCK TYPES AND MAP ROCKS & SOILS	• UNIVER. OF KANSAS - DEVELOPMENT OF INTERPRETING ACTIVE MW DATA • ERIM - X-L BAND SLAR EVALUATION • ERIM - IN COOPERATION WITH USGS TO INVESTIGATE FEASIBILITY OF TECHNIQUE	• EVALUATION OF GEOLOGICAL INFORMATION CONTENT IN ACTIVE MW IMAGERY • DETAILED FEASIBILITY STUDY TO EVALUATE PRACTICABILITY OF AUTOMATED METHODS TO IDENTIFY ROCK TYPES & PREPARE SURFACE MAPS UNDER VARIOUS FIELD CONDITIONS & USING SCANNER SUCH AS MSDS (24 CHANNELS)

• DEVELOPMENT OF THERMAL IR SCANNERS - TO DISCRIMINATE SURFACE ANOMALIES CAUSED BY GEOTHERMAL ACTIVITY, MONITOR VOLCANIC ACTIVITY, AND DETECT SOIL MOISTURE CONTENT/STATE (e.g. - FROZEN) TO ASSESS LANDSLIDE & PERMAFROST HAZARDS, DISCRIMINATE ROCK TYPES BY "THERMAL INERTIA" TECHNIQUES
• PASSIVE MW SURFACE TEMPERATURE SIGNATURES - TO DETECT SURFACE TEMP ANOMALIES CAUSED BY GEOTHERMAL ACTIVITY
• GEOTHERMAL MODELING
• LANDSLIDE MODELING
	• GSFC - NIMBUS V SURFACE COMPOSITION MAPPING RADIOMETER EXPERIMENT - PROPOSED "HEAT CAPACITY MAPPING MISSION"
	• JPL - CORRELATION OF PASSIVE MW SIGNATURES TO DEPTH INFORMATION OF KNOWN GEOTHERMS
	• AMES - LANDSLIDE MODELING
		• HIGHER RESOLUTION THERMAL SCANNERS (.25 - .5 C) TO:
		  • DISCRIMINATE SIGNIFICANT GEOTHERM ANOMALIES
		  • ASSESS IMPENDING VOLCANIC ERUPTIONS
		  • DETECT SOIL MOISTURE CHANGES RELATED TO LANDSLIDES
		  • DETECT ZONES OF PERMAFROST DEVELOPMENT
		  • TEST "THERMAL INERTIAL" METHOD OF IDENTIFYING ROCK TYPES
		• GEOTHERMAL MODELING TO RELATE SURFACE TEMP TO DEPTH INFORMATION
		• LANDSLIDE MODELING TO RELATE CHANGES IN SOIL MOISTURE TO DEVELOPMENT OF LANDSLIDES

Figure III-11. Mineral resources, geologic structure, and landform surveys.

OBJECTIVES *	CURRENT STATUS USING ERTS DATA	POTENTIAL ASVT'S
SNOW/ICE SURVEYS • SNOW MAPPING • LAKE ICE MONITORING • GLACIER SURVEYS	• EASILY DISTINGUISHED IN 0.6 - 0.7 μm REGION • SNOW LINE ELEVATION ESTIMATED TO WITHIN 60 METERS • SNOW AREA WITHIN ± 5% • CAN DISTINQUISH SURGING GLACIERS FROM NON-SURGING GLACIERS • SEVERAL ICE TYPES AND THEIR CHARACTERISTICS CAN BE SEEN • ICE CRACKS AND LEADS OF 70 - 80 METERS CAN BE SEEN	ERTS • CONTINENTAL OR GLOBAL SNOW/ICE MAPPING USING ERTS/NOAA-2 COMBINATIONS FUTURE • QUANTITATIVE SNOW/ICE MAPPING
SURFACE WATER MAPPING	• CAN EASILY IDENTIFY WATER IN 0.8 - 1.1 μm REGION • FLOODED AREA IDENTIFIABLE 1 - 2 WEEKS AFTER FLOOD • FLOOD PRONE AREAS CAN BE DELINEATED PRIOR TO FLOODING • WATER BODIES AS SMALL AS 3 ACRES CAN BE DETECTED USING DIGITAL TECHNIQUES • FLOODED AREA CAN BE MEASURED TO ± 5% WITH PHOTO INTERPRETATION AND ± 2% WITH DIGITAL TECHNIQUES • FLOOD MAPPING TO 1:100,000 SCALE • SOME RIVER CHANNEL CHARACTERISTICS CAN BE MEASURED • CAN OBSERVE RIVERS AS NARROW AS 70 METERS	ERTS • SURFACE WATER MAPPING FUTURE • FLOOD MAPPING AT 1:24,000 • SURFACE WATER MAPPING AT HIGHER RESOLUTION
WATER QUALITY SURVEYS	• RELATIVE TURBIDITY AND ALGAL CONTENT WITHIN AND BETWEEN WATER BODIES CAN BE SEEN • 0.6 - 0.7 μm BEST FOR OBSERVING TURBIDITY VARIATIONS	ERTS • RELATIVE WATER QUALITY MONITORING FUTURE • QUANTITATIVE WATER QUALITY MONITORING
ESTUARY & WETLANDS SURVEYS	• CAN MAP MARSH-WATER INTERFACE, PLANT COMMUNITIES, & UPPER WETLAND BOUNDARY ALL RELIABLY ON 1:125,000 SCALE • AREA EXTENT OF WETLANDS CAN BE MAPPED • ERTS OBSERVATION FREQUENCY IS ADEQUATE	ERTS • WETLANDS MAPPING AT 1:125,000 SCALE FUTURE • WETLANDS MAPPING AT 1:24,000 SCALE • MONITORING WETLAND DYNAMICS
SUB-SURFACE WATER SURVEYS	• ERTS DETECTION OF FRACTURE ZONES AND INTERSECTION OF FRACTURES HAS POTENTIAL FOR ADDITIONAL DEVELOPMENT OF GROUND WATER RESOURCES (POTENTIALLY HIGH YIELD GROUND WATER WELLS CAN BE DRILLED ALONG FRACTURE ZONES) • RELATIVE DIFFERENCES IN SOIL MOISTURE ARE IDENTIFIABLE • IDENTIFICATION OF VEGETATION INDICATORS OF SUB-SURFACE WATER	ERTS • ERTS DATA TO AID GROUND WATER EXPLORATION
WATER USE SURVEYS	• CAN IDENTIFY IRRIGATED AREAS IN ARID AND SEMI-ARID AREAS AND MEASURE THEIR AREA WITHIN ± 5% OVER LARGE AREAS	ERTS NONE FUTURE • MEASUREMENT OF WATER USE USING REMOTE SENSING (IRRIGATION, EVAPOTRANSPIRATION BASED ON VEGETATION COVER, LEAKS)
WATERSHED SURVEYS	• MAP LAND USES RELATED TO WATER AT 1:250,000 • CAN INDICATE WATER LEVEL BY APPEARANCE OR DISAPPEARANCE OF FEATURES AROUND SHORE • AREAS MEASURED TO ± 5% PHOTO-INTERPRETATION ± 2% DIGITAL TECHNIQUES	ERTS • DEMONSTRATE SELECTED WATERSHED MODELS • TVA • FEATHER RIVER • WIND RIVER FUTURE • WATERSHED MODEL DEMONSTRATION • SPACE MONITORING OF PRECIPITATION AMOUNTS • FLOOD PREDICTION

* IN ORDER OF PRIORITY

Figure III-12. Water resources.

RESEARCH & TECHNOLOGY AREAS	PLANNED OR UNDERWAY	NEEDED
• MODEL DEVELOPMENT RELATING SNOW COVER TO RUNOFF PREDICTION • SNOW MAPPING IN FORESTED AREAS • TECHNIQUE FOR EXTRA POLATION OF POINT SNOW DEPTH AND MOISTURE TO AREA MEASUREMENT OF ERTS IMAGE • INVESTIGATE UTILITY OF .8 - 1.1 μm BAND FOR MEASURING SNOW MELT • EXPLOIT ERTS IN COMBINATION WITH OTHER PLATFORMS SUCH AS NOAA-2 AND NIMBUS • DEVELOP ACTIVE/PASSIVE M/W SYSTEMS AND DATA ANALYSIS TECHNIQUES • DEVELOP DIGITAL TECHNIQUES	• IDENTIFICATION OF LAKE ICE • ERTS/NIMUS/OTHERS FOR SNOW MAPPING RUNOFF PREDICTION • MICROWAVE SYSTEM DEVELOPMENT • AREAL EXTENT MELT RELATIONSHIP	• DEVELOP SPACE CAPABILITY FOR RIVER AND LAKE ICE MAPPING AND MONITORING • DEVELOP TECHNIQUE FOR MEASURE OF ICE TYPE AND THICKNESS • REFINE EXISTING MODELS TO USE REMOTE SENSING SNOW MAP DATA IN COMPUTING RUNOFF • DEVELOP DIGITAL TECHNIQUES FOR SNOW/ICE MAPPING • MEASUREMENT OF SNOW DEPTH AND MOISTURE CONTENT
• INCREASED OBSERVATION FREQUENCY FOR STUDY OF WATER DYNAMICS • DEVELOP MODELS OF LAKES AND RIVER PROCESSES • EXPLORE DIGITAL TECHNIQUES FOR LARGER SCALE MAPPING	• EXPLORATION OF DIGITAL TECHNIQUES FOR LARGER SCALE MAPPING	• STUDY OF WATER DYNAMICS • REVISION OF LAKE AND RIVER PROCESS MODELS TO ACCEPT REMOTE SENSING INPUTS • DEVELOP AREA VOLUME RELATIONSHIPS AND MEASUREMENT TECHNIQUES
• EXTEND SPECIFIC AREA ERTS RESULTS TO OTHER AREAS • EUTROPHICATION MODEL USING ERTS DATA INPUTS • QUANTIFY SEDIMENT AND OTHER POLLUTANTS RELATIONSHIP WITH ERTS MEASUREMENTS	• DELINEATION OF SOURCES OF WATER QUALITY AND QUANTITATIVE CORRELATION WITH REFLECTANCE OR EMITTANCE • EXTENSION OF ERTS RESULTS TO OTHER AREAS	• QUANTIFY WATER QUALITY MEASUREMENTS AND MOST EFFECTIVE MEASUREMENT TECHNIQUES
• IMPROVE VEGETATION CLASSIFICATION • DEVELOP IMPROVED MODELS OF WETLAND VALUE • HIGHER RESOLUTION FOR MAPPING AT LARGER SCALE • EXPLORE DIGITAL TECHNIQUES FOR IMPROVED MAPPING • MORE QUANTITATIVE MODELS RELATIVE TO WETLANDS WILDLIFE SUPPORT	• MAPPING OF MARSH/WATER INTERFACE, PLANT COMMUNITIES, AND UPPER WETLAND BOUNDARY • EXPLORATION OF DIGITAL TECHNIQUES	• IMPROVED VEGETATION CLASSIFICATION • IMPROVED MODELS FOR WETLANDS WILDLIFE SUPPORT AND WETLAND VALVE
• DEVELOP TECHNIQUES FOR LOCATION OF GROUND WATER WITH BETTER DOCUMENTATION OF SUCCESS • QUANTITATIVE SOIL MOISTURE MEASUREMENTS • IMPROVED IDENTIFICATION OF VEGETATION INDICATORS	• SOIL MOISTURE MEASUREMENT TECHNIQUES	• EVALUATION OF OTHER PLATFORMS (NIMBUS, NOAA-2, OTHER TO AID AND SUPPLEMENT ERTS FOR SUB-SURFACE WATER SURVEYS • QUANTIFY RELATIONSHIP BETWEEN VEGETATION INDICATORS AND SUB-SURFACE WATER
• QUANTIFY RELATIONSHIP BETWEEN VEGETATION COVER/VIGOR AND EVAPOTRANSPIRATION • SPECIFY WATER USE REMOTE SENSING MEASUREMENTS • FURTHER DEVELOP TECHNIQUES FOR DELINEATION OF PHREATOPHYTE AND RIPARIAN PLANT COMMUNITIES	• WATER USE MEASUREMENTS	• MODELS OF VEGETATION/EVAPOTRANSPIRATION RELATIONSHIP

• DEVELOP TECHNIQUES FOR REMOTE SENSING MEASUREMENTS OF PRECIPITATION
• DEVELOP TECHNIQUES FOR MEASURING WATER VOLUMES
	• USE OF ERTS DCS TO RELAY IN-SITU POINT MEASUREMENTS
	• MAPPING OF AERIAL EXTENT OF SNOW
	• DEMONSTRATION OF SELECTED WATERSHED MODELS
	  • TVA
	  • FEATHER RIVER
	  • WIND RIVER
		• REMOTE MEASUREMENT OF PRECIPITATION USING FAR IR AND MICROWAVE
		• DEVELOPMENT OF GENERALLY APPLICABLE WATERSHED MODEL

Figure III-13. Water resources.

OBJECTIVES*	CURRENT STATUS USING ERTS DATA	POTENTIAL ASVT'S
COASTAL PROCESSES • EROSION • SEDIMENTATION • CIRCULATION • WATER COLOR • BATHYMETRY	• NEARSHORE CIRCULATION (CURRENT) PATTERNS, DIRECTION OF NET WATER TRANSPORT, AND BOUNDARIES BETWEEN DIFFERENT WATER MASSES CAN BE DETERMINED USING SEDIMENT AS A TRACER • DETECTION AND MONITORING OF RIVER SEDIMENT PLUMES • RELATIVE DEPTHS DOWN TO 20 METERS CAN BE DETERMINED IN CLEAR WATER • LIMITED SUCCESS IN QUANTITATIVE MEASUREMENT OF SUSPENDED SEDIMENT	FUTURE • CONTINENTAL SHELF CIRCULATION • SHALLOW WATER CHARTING • MANAGEMENT AND PRESERVATION OF COASTAL RESOURCES • BAY/ESTUARIES MODELING
LIVING MARINE RESOURCES • LOCATION • IDENTIFICATION • CORRELATION WITH PARAMETERS	• CORRELATIONS BETWEEN VARIATIONS IN RADIANCE DATA FROM THE ERTS MSS AND SURFACE-ACQUIRED CHLOROPHYLL AND TURBIDITY DATA WERE DEMONSTRATED • LOCATION OF MENHADEN FISH RELATIVE TO CERTAIN WATER TURBIDITY, COLOR AND CHLOROPHYLL BOUNDARIES HAS BEEN DEMONSTRATED	FUTURE • DISTRIBUTION AND ABUNDANCE OF LIVING MARINE RESOURCES OF PRINCIPLE IMPORTANCE TO THE UNITED STATES
SEA ICE • LOCATION • BOUNDARIES • MOVEMENT	• SEA ICE CAN BE DETECTED AND DISTINGUISHED FROM CLOUDS. • ICE FEATURES OF ARCTIC LATITUDES CAN BE TRACKED FOR SEVERAL DAYS • MELT WATER ON ICE AND SNOW LINES ON GLACIERS CAN BE INFERRED • INFORMATION ON ICE TYPE, SIZE, AND CONCENTRATION CAN BE OBTAINED	ERTS • MAP SEA ICE BOUNDARIES AND MOVEMENT FUTURE • DYNAMICS OF SEA ICE (PREDICTION OF ICE MOVEMENT AND DEFORMATION)
OCEAN DYNAMICS • CIRCULATION • TEMPERATURE • SEA STATE	• CURRENT BOUNDARIES ARE OBSERVABLE AS COLOR DIFFERENCES	FUTURE • MONITOR OPEN OCEAN DYNAMICS (SURFACE WAVES, AIR-SEA INTERFACE, CURRENTS, AND MARINE GEOID)

*IN ORDER OF PRIORITY

Figure III-14. Marine resources and ocean surveys.

RESEARCH AND TECHNOLOGY AREAS	PLANNED OR UNDERWAY	NEEDED
EROSION • IMAGERY OF HIGHER RESOLUTION FOR STUDY OF BEACH AND SHORELINE DYNAMICS SEDIMENTATION • TIME HISTORY OF SEDIMENT PLUMES CIRCULATION • MEASURING COASTAL WATER CIRCULATION WATER COLOR • INTERPRET WATER COLOR IN TERMS OF SPECIFIC PARAMETERS BATHYMETRY • DEVELOP DATA INTERPRETATION TECHNIQUES WHICH INCORPORATE SUB-SURFACE TRUTH MEASUREMENTS	• TECHNIQUES FOR IDENTIFICATION OF SEDIMENT BOUNDARIES & CONCENTRATION CONTOURS, ACCUMULATION OF TOXIC FOAMS AND SURFACE SLICKS, DISPERSION OF OIL AND OTHER POLLUTANTS, TIDAL FRONTS AND CIRCULATION PATTERNS, THERMAL DISCHARGE PLUMES AND ISOTHERMS, COASTAL VEGETATION AND TIDAL MARSH ENCROACHMENT, AND COASTAL EROSION • MAPPING OF WATER COLOR, CIRCULATION, SEDIMENT PLUMES, AREAS OF WAVE AND CURRENT EROSION, AND VEGETATION • DETERMINATION OF EFFECT OF TIDAL, CURRENT, AND SEASONAL VARIATIONS ON WATER TARGET SIGNATURES • MODEL DEVELOPMENTS FOR WAVE DYNAMICS, CURRENTS, AND POLLUTION DISPERSAL • INVESTIGATION OF PASSIVE MICROWAVE RADIOMETRIC SCANNING TO OCEANOGRAPHY	• IMAGERY OF HIGHER RESOLUTION • DEVELOP CAPABILITY TO PERFORM TIME HISTORY ANALYSIS OF SEDIMENT PLUMES • WATER CIRCULATION MODELS • CONTINUE DEVELOPMENT OF TECHNIQUES FOR INTERPRETING WATER COLOR IN TERMS OF SPECIFIC PARAMETERS • IDENTIFICATION OF RELATIONSHIPS BETWEEN MEASURABLE OCEANOGRAPHIC PARAMETERS AND CIRCULATION • CONDUCT BASIC RESEARCH IN SEDIMENT LOAD SIGNATURES • DEVELOP ATMOSPHERIC CORRECTION TECHNIQUES
CORRELATION WITH ENVIRONMENTAL PARAMETERS • UNDERSTANDING OF RELATIONSHIPS BETWEEN ENVIRONMENTAL AND BIOLOGICAL PARAMETERS IS REQUIRED • NEED CAPABILITY TO QUANTITATIVELY MEASURE CHLOROPHYLL, SALINITY, TURBIDUTY, AND SURFACE TEMPERATURE LOCATION AND IDENTIFICATION • NEED CAPABILITY FOR LOCATION IDENTIFICATION AND TRACKING SYSTEMS FOR FISH STOCKS AND MARINE ANIMALS	• RELATIONSHIP OF ENVIRONMENTAL PARAMETERS TO FISH CATCHES AND FISH DISTRIBUTIONS • RECOGNITION OF WETLAND VEGETATION • ECOSYSTEM POLLUTION EFFECTS MODELS • TECHNIQUE DEVELOPMENT FOR REMOTELY MEASURING WATER SURFACE TEMPERATURE, SALINITY, AND WATER COLOR • INVESTIGATION OF EFFECTS OF ATMOSPHERIC TRANSMISSIVITY ON MEASUREMENT OF OCEAN FLOOR • INTERPRETATION AND ANALYSIS OF COLORS AND PATTERNS IN SEA WATER IN TERMS OF PLANKTON COMMUNITIES AND CHLOROPHYLL • ESTIMATION OF PLANKTON PRODUCTIVITY IN UPWELLING AREAS	• CONTINUE DEVELOPMENT OF CAPABILITY TO QUANTITATIVELY MEASURE CHLOROPHYLL, SALINITY, TURBIDITY, AND SURFACE TEMPERATURE • MODELS RELATING ENVIRONMENTAL AND BIOLOGICAL PARAMETERS • CONTINUE INVESTIGATIONS OF ATMOSPHERIC TRANSMISSIVITY
SEA ICE • GREATER SPATIAL RESOLUTION FOR DETECTION OF ICEBERG HAZARDS. DETERMINE SEASONAL AND STORM INDUCED EFFECTS ON SEA ICE	• TECHNIQUES FOR ANALYSIS OF SEA ICE AND SURFACE TEMPERATURES, MEASUREMENT OF ICE THICKNESS, AND INVENTORYING ICE BERGS AS A FUNCTION OF SIZE • DETERMINATION OF SPECTRAL INTERVAL MOST SUITABLE FOR ICE SURVEY	• MODELS FOR PREDICTING ICE MOVEMENT • DETECT ICE THROUGH CLOUDS AND UNDER NIGHT-TIME CONDITIONS
CIRCULATION • MORE DSC'S ON DRIFTING BUOYS AND ICE FLOES ARE NEEDED THERMAL FEATURES AND SEA STATE • CONTINUE RESEARCH ON MICROWAVE RADIOMETRY FOR TEMPERATURE AND SEA STATE MEASUREMENTS	• TECHNIQUES FOR LOCATING CURRENTS, STUDYING THERMAL BOUNDARIES, SHIFTS AND RATE OF FLOW, MEASUREMENT OF SEA STATE, LOCATING BIOLOGICALLY RICH AREAS, DETECTING NAVIGATIONAL HAZARDS, PRESENCE OF SEDIMENT, OCEAN CIRCULATION PATTERNS, MEASUREMENT OF SURFACE WINDS, AND IDENTIFYING SURFACE FISH OIL FILMS	• MORE DSC'S ON DRIFTING BUOYS AND ICES FLOES • INVESTIGATION OF MICROWAVE SENSORS FOR INFERENCE OF SEA STATE CHARACTERISTICS • INVESTIGATE RELATIONSHIP BETWEEN SUN GLINT AND SEA STATE

Figure III-15. Marine resources and ocean surveys.

OBJECTIVES *	CURRENT STATUS USING ERTS DATA	POTENTIAL ASVT'S
WATER QUALITY • POLLUTANTS • THERMAL EFFLUENTS • SALT WATER INCURSION • EUTROPHICATION	• TECHNIQUES FOR REMOTE SENSING OF OIL HAVE BEEN DEMONSTRATED • CHEMICAL DISCHARGES FROM INDUSTRIAL PLANTS CAN BE DETECTED • SEDIMENT (TURBIDITY) AND DIFFERENCES IN SEDIMENT CONTENT WITHIN RIVERS, BAYS, LAKES, AND RESERVOIRS IS EASILY DISCERNIBLE • OCEAN DUMPING OF INDUSTRIAL WASTES IS DETECTABLE. MONITORING OF DUMPING LOCATIONS TO ASSURE COMPLIANCE WITH REGULATIONS IS POSSIBLE • RATE AND EXTENT OF BEACH EROSION CAN BE EVALUATED • DETECTION OF ALGAL BLOOMS AND RED-TIDE ENCROACHMENT ON FRESH AND SALINE BODIES IS POSSIBLE • THERMAL VARIATION IN WATER'S SURFACE CAN BE DETECTED • AREAS WHERE WASTES CAN BE CONCENTRATED BECAUSE OF CURRENTS CAN BE IDENTIFIED	ERTS • LAKE EUTROPHICATION MONITORING FUTURE • BAY THERMAL POLLUTION MONITORING • INTEGRATED POLLUTION MONITORING SYSTEM FOR MAJOR COASTAL REGION
WILDLIFE MONITORING • MIGRATIONS • HABITATS • FISH & GAME AREAS	• SEASONAL CHANGES IN SNOW COVER CAN BE MAPPED • FEATURES SUCH AS SMALL STREAMS CAN BE DETECTED • FEASIBILITY OF USING ERTS-1 IMAGERY TO MAP BOTANICAL COMMUNITY TYPES IS INDICATED	ERTS • WILDLIFE HABITAT SENSING AND EVALUATION FUTURE • TRACKING AND MONITORING OF MAJOR WILDLIFE SPECIES
GENERAL ENVIRONMENTAL ASSESSMENTS • SHORT LIVED EVENTS • PUBLIC HEALTH	• SHORT LIVED EVENTS SUCH AS FOREST FIRES, OIL SPILLS, VEGETATION DAMAGE, VOLCANOES, STORM RIDGES, AND EARTHQUAKES HAVE BEEN DETECTED	
LAND/VEGETATION QUALITY • ECOLOGICAL MODELS • MAN'S IMPACT	• STRIP MINES, TAILING PILES, AND DENUDATION FROM PROJECTS SUCH AS HIGHWAY CONSTRUCTION ARE DETECTABLE • HAZARDS RELATED TO UNDERGROUND MINES WHICH HAVE BEEN DISTURBED BY STRIP MINING HAVE BEEN OBSERVED • MONITORING OF REVEGETATION OF MINE DUMPS HAS BEEN DEMONSTRATED • VEGETATION MAPS TO A SCALE OF 1:250,000 HAVE BEEN PRODUCED	ERTS • ASSESSMENT OF STRIP MINING AND MONITORING OF RECLAMATION EFFORTS FUTURE • MONITOR ACTIVITIES IN A HIGHLY DYNAMIC REGIONAL AREA

* IN ORDER OF PRIORITY

Figure III-16. Environment.

RESEARCH AND TECHNOLOGY AREAS	PLANNED OR UNDERWAY	NEEDED
• DEVELOP TECHNIQUES FOR QUANTITATIVE ANALYSIS OF OIL SPILLS • IDENTIFICATION OF EFFLUENT SUBSTANCES WHICH ALTER WATER COLOR • DETECTION OF PESTICIDES, HERBICIDES, SPECIFIC SEWAGE COMPONENTS, HEAVY METALS, CHLORINATED HYDROCARBONS, AND OTHER SYNTHETIC ORGANICS • DETECTION OF SOLID WASTES • DEVELOPMENT OF MICROWAVE SENSORS AND TECHNIQUES FOR SENSING SURFACE TEMPERATURE THROUGH CLOUDS	• DETECTION AND MONITORING OIL POLLUTION AND WASTE DUMPING • DEVELOPMENT OF TECHNIQUES FOR DETECTION AND ANALYSIS OF LAKE EUTROPHICATION, WATER COLOR, DISPERSION OF EFFLUENTS FROM OCEAN OUTFALLS, SUSPENDED SOLIDS AND SEDIMENT, CIRCULATION DYNAMICS, ALGAL BLOOMS, TIDAL AND OFFSHORE CURRENTS, AND CHEMICAL POLLUTANTS SUCH AS FERTILIZERS, HERBICIDES, SYSTEMICS, DETERGENTS, INSECTICIDES, ETC. • DEVELOPMENT OF TECHNIQUES FOR WETLAND MAPPING AND EVALUATION • MODELING OF LAKE CIRCULATION AND EFFECTS OF CONSTRUCTION AND STAGED FILLING OF RESERVOIRS	• DEVELOP CAPABILITY TO QUANTITATIVELY IDENTIFY POLLUTANTS • MODELS OF BAY/ESTUARY SYSTEMS • DEVELOP SENSORS FOR ALL WEATHER, DAY OR NIGHT, COVERAGE
• DEVELOP SPECIES SIGNATURES • DEVELOP LIGHTWEIGHT, MINIATURE TRANSMITTING EQUIPMENT INCLUDING ANTENNAS, POWER PACKS, HARNESSES AND SURGICAL IMPLANT TECHNIQUES • DEVELOP HIGH RESOLUTION PHOTOGRAPHY, MSS AND IR SENSORS • DEVELOP RADAR ENERGY ACTIVATED RETRANSMITTER • IMPROVED TECHNIQUES FOR FISH SCALE ANALYSIS • DEVELOP TECHNIQUES FOR NUMERICAL ASSESSMENT AND IDENTIFICATION OF WILD ANIMAL STOCKS	• DEVELOPMENT OF AUTOMATIC DATA PROCESSING TECHNIQUES FOR DETECTING AND PLOTTING WATER BODIES, LAND CLASSIFICATION, AND COMPUTATION OF LAND AREAS • EVALUATION OF SEASONAL CHANGES IN SURFACE CONDITIONS AND CHANGES IN LAND USE • LOCATION AND MAPPING OF ENVIRONMENTAL FEATURES RESULTING FROM ACTIVITIES OF LARGE HERDS OF CARIBOU • DEVELOPMENT OF BIO-INSTRUMENTATION EQUIPMENT AND TECHNIQUES • ANALYSIS OF MIGRATION PATHWAYS AND BEHAVIORAL CHARACTERISTICS OF GRAY WHALES	• CONTINUE DEVELOPMENT OF LIGHTWEIGHT, MINIATURE TRANSMITTING EQUIPMENT AND SURGICAL IMPLANT TECHNIQUES • TECHNIQUES FOR NUMERICAL ASSESSMENT AND IDENTIFICATION OF WILDLIFE SPECIES • TECHNIQUES FOR MONITORING WILDLIFE MIGRATION
	• DETECTION AND MONITORING OF SHORT LIVED EVENTS • DETECTION AND MONITORING OF LOCUST BREEDING SITES • DEVELOPMENT OF REMOTE SENSING TECHNIQUES FOR ASSISTING IN ERADICATION OF SCREWWORMS • ANALYSIS OF EARTH RESOURCES DATA TO DETERMINE ITS SUITABILITY AND APPLICABILITY TO LIFE SCIENCES	• DEVELOP TECHNIQUES FOR MONITORING ENVIRONMENTAL CONDITIONS AFFECTING PUBLIC HEALTH
• IMPROVED RESOLUTION TO PERMIT DETECTION OF SOLID WASTE DISPOSAL AND DENUDATION RESULTING FROM CONSTRUCTION SITES	• TECHNIQUES FOR DETECTING, MONITORING, AND MAPPING STRIP MINES • EVALUATION OF EFFECTS AND RECLAMATION ACTIVITIES AROUND STRIP MINES • MONITORING OF GROWTH AND DECLINE OF VEGETATION ON OR DOWN STREAM FROM MINE DUMPS • IDENTIFICATION OF VEGETATION CHANGES DUE TO HIGHWAY CONSTRUCTION, SALTING, DRAINING, AND LANDFILL • EVALUATION OF RESULTS OF CONSTRUCTION AND OPERATION OF THE OAKLEY RESERVOIR • DETERMINATION OF SPECTRAL SIGNATURES OF DOMINANT DESERT PLANT SPECIES	• CAPABILITY TO MONITOR CONSTRUCTION SITE SOLID WASTE DISPOSAL AND DENUDATION

Figure III-17. Environment.

(3) Shuttle Experiment Definitions. Shuttle experiment definitions are being defined for Shuttle Sortie missions. These experiments will take advantage of such features as onboard automatic data processing and visual displays of remote sensor images, which can facilitate astronaut participation. Current efforts include studying the modular scanning spectroradiometer, standard earth observations package, and imaging radar systems for the Shuttle vehicle. Another major study is aimed at defining the total earth resources system for the Shuttle era.

(4) Earth Observatory Satellite. The EOS is the first of a planned series of orbital platforms for conducting research on advanced remote sensors and techniques applicable to earth observations by building on proven systems developed for ERTS, Nimbus, and other spacecraft. Principal features will be an improved capability for spacecraft position and attitude determination, increased viewing area for sensors, and a high-data-rate (200 millibits/second) storage and transmission system. The sensors under development for EOS will significantly advance existing capabilities for acquiring experimental earth resources data. The program provides for studies of spacecraft subsystems and data management approaches, and for design modifications to the data handling systems. In support of oceanographic and meteorological investigations, including air-sea interaction, it is planned to test a multifrequency, passive, microwave sensor system on some EOS missions. This research is an essential step in the development of an all-weather remote-sensing capability.

b. Complementary Flight Programs and Demonstrations. Multidiscipline projects which develop capabilities for the earth observations program in general complement the discipline efforts of earth resources, weather and climate, and pollution. There are currently two such projects which complement the earth resources discipline.

(1) Advanced Applications Flight Experiments. The AAFE Program is concerned with developing potential experiments for future spacecraft missions — either conventionally launched automated satellities or Shuttle missions. Development of the experiments proceeds without commitments to a specific mission and continues only until their usefulness and effectiveness for becoming flight candidates are demonstrated. Those instruments not meeting the projected or anticipated results are eliminated prior to the expensive flight development.

Emphasis is placed on developing state-of-the art instrumentation and technology for the several earth observations disciplines. Efforts involve development of ancillary and support systems as well as remote sensors. Within the earth resources applications area, remote sensing instrumentation includes such devices as the radiometer/scatterometer (RADSCAT), high resolution pointable imager, and fraunhofer line discriminator. The RADSCAT was flight tested on a C130 aircraft in 1973 and demonstrated its capability to measure sea surface roughness. It was also used to underfly the Skylab in support of earth resources experiments.

Support system technology developments are aimed at providing the ancillary equipments necessary for advanced sensing systems. High-data-rate tape recorders and systems for precision attitude determination and hybrid multispectral data processing are being developed.

(2) Heat Capacity Mapping Mission. The HCMM is a small, low cost, special purpose Applications Technology Satellite mission planned for launch in 1977. The prime objectives are to obtain thermal inertia measurements for rock and soil mapping, to investigate the feasibility of locating geothermal resolution data for hydrologic and agricultural applications. A sun synchronous orbit is planned at approximately 600 km designed to acquire data at the daily maximum and minimum temperature fluctuations. A two-channel scanner operating in the near infrared and thermal infrared regions is planned.

(3) Demonstrations. A major thrust of the program during the second half of the 1970's will be demonstrations of cost effective systems for selected applications. Exploratory investigations conducted with ERTS, EREP, and aircraft data that have proven feasible and hold promise of being cost effective will be selected for further development to verify the application. Verification testing will be an integrated test of the total technical capability required to accomplish a specific application objective. The tests will be designed to perform a thorough evaluation of an application system's capability, to measure and quantize its reliability and accuracy, and to furnish all the information necessary for a potential user to make a decision regarding implementing the technology in an operational system. Several such potential applications have been identified. Figure III-18 identifies and indicates the earliest flight projects with which they can be conducted. It is planned to initiate a selected few in FY-75.

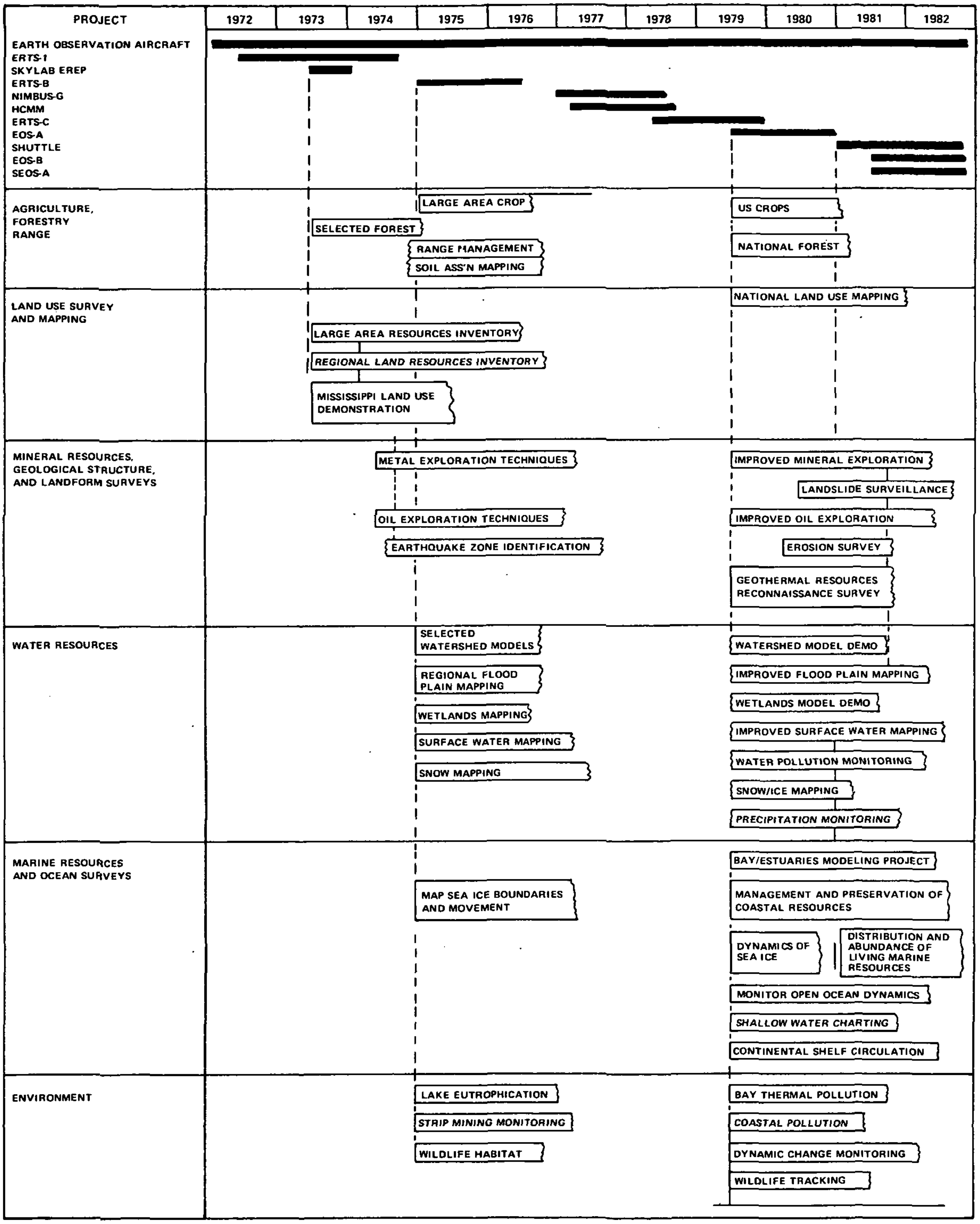

Figure III-18. Potential demonstration projects.

c. Flight Programs. The flight projects serve two purposes within the program at the present time: (1) provide test platforms for the development and transmission systems, remote sensing techniques, and subsystems technology and (2) provide a source of data for applications investigations and demonstration. Figure III-19 summarizes the current and projected flight projects, their purposes, and unique characteristics.

(1) Earth Resources Technology Satellite. ERTS-1 is the first spacecraft system designed specifically for earth resources surveys. It has operated continuously since launch in July 1972 providing experimental data for over 350 domestic and foreign investigations in all discipline areas. The experience gained with this prototype of future space systems will provide invaluable. The results of the investigations have made the experiment an unqualified success. Several applications in each discipline area have been proven feasible and identified as potential candidates for Application System Verification Tests (ASVT's). The orbital parameters, sensor spatial quality, and data quality have proven so successful that the Department of Interior is giving serious consideration to acquiring a slightly modified ERTS for the first operational system.

Although the ERTS is a U.S. facility, it is acquiring data over many foreign countries for over 100 foreign investigators who are conducting evaluations of the data for resources applications. These investigations are sponsored and supported by their respective countries with the U.S. providing the data. The data acquired is in the public domain and obtainable for the cost of reporduction only at the U.S. Department of Interior's Earth Resources Observation System data center at Sioux Falls, South Dakota.

The experience gained at the NASA Data Processing Facility (NDPF) at Goddard Space Flight Center, where all the telemetered data are processed prior to simultaneous release to the investigators and the EROS data center, has answered many of the questions concerning the handling and processing of a continuous flow of large quantities of data.

With all of its successes and the knowledge gained from ERTS, it is still the "Model T" of earth resources space remote sensing systems. Many improvements and advances are necessary to satisfactorily meet application requirements. Figure III-20 depicts some anticipated data acquisition, processing, and dissemination growth trends. Increased temporal and spectral coverage are required for many applications. A fifth band in the thermal infrared region is under development for a later ERTS mission; however, extension of spectral coverage to the microwave region is necessary for all weather acquisition and offers considerable promise for many applications.

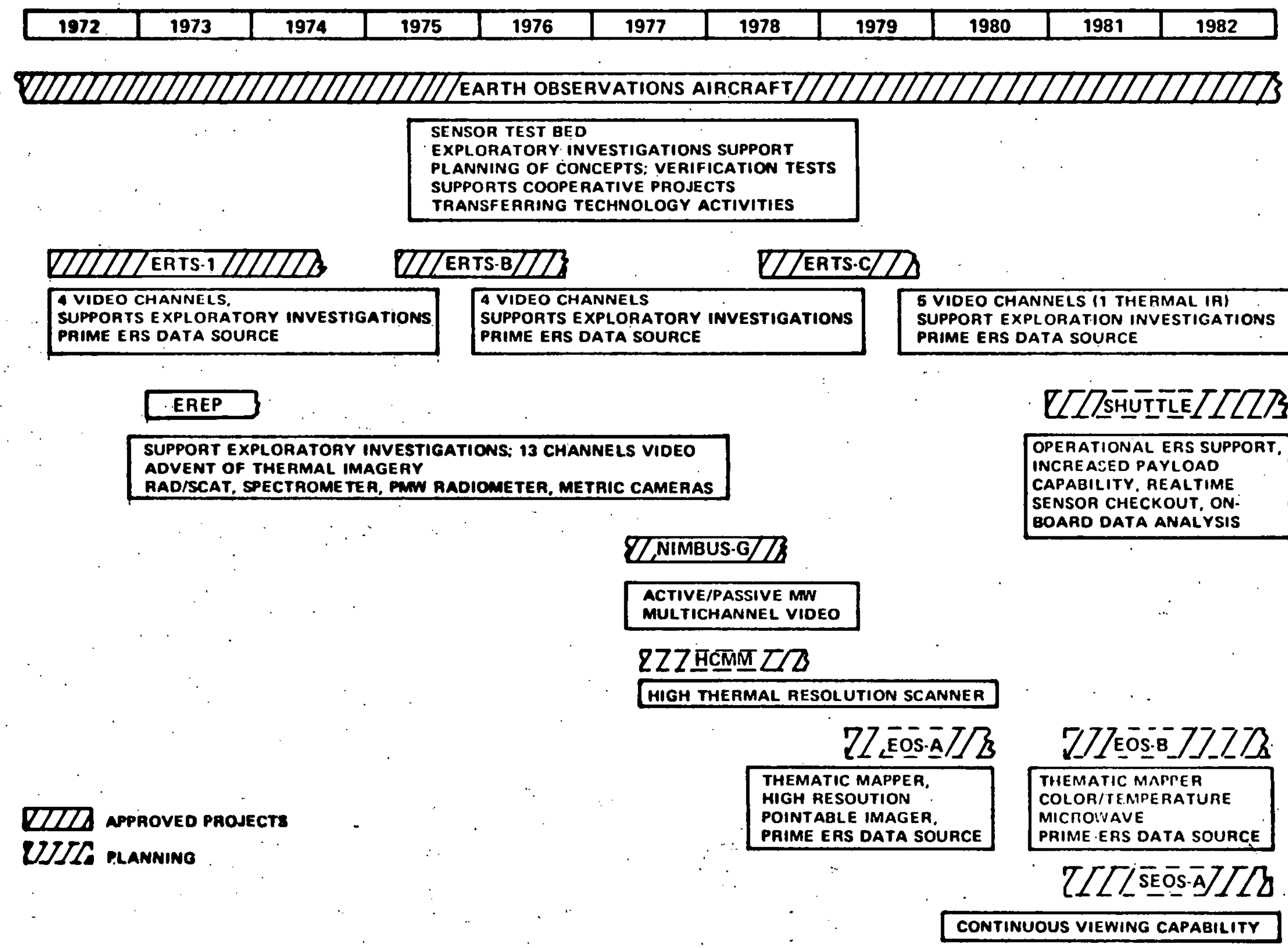

Figure III-19. ERS flight projects.

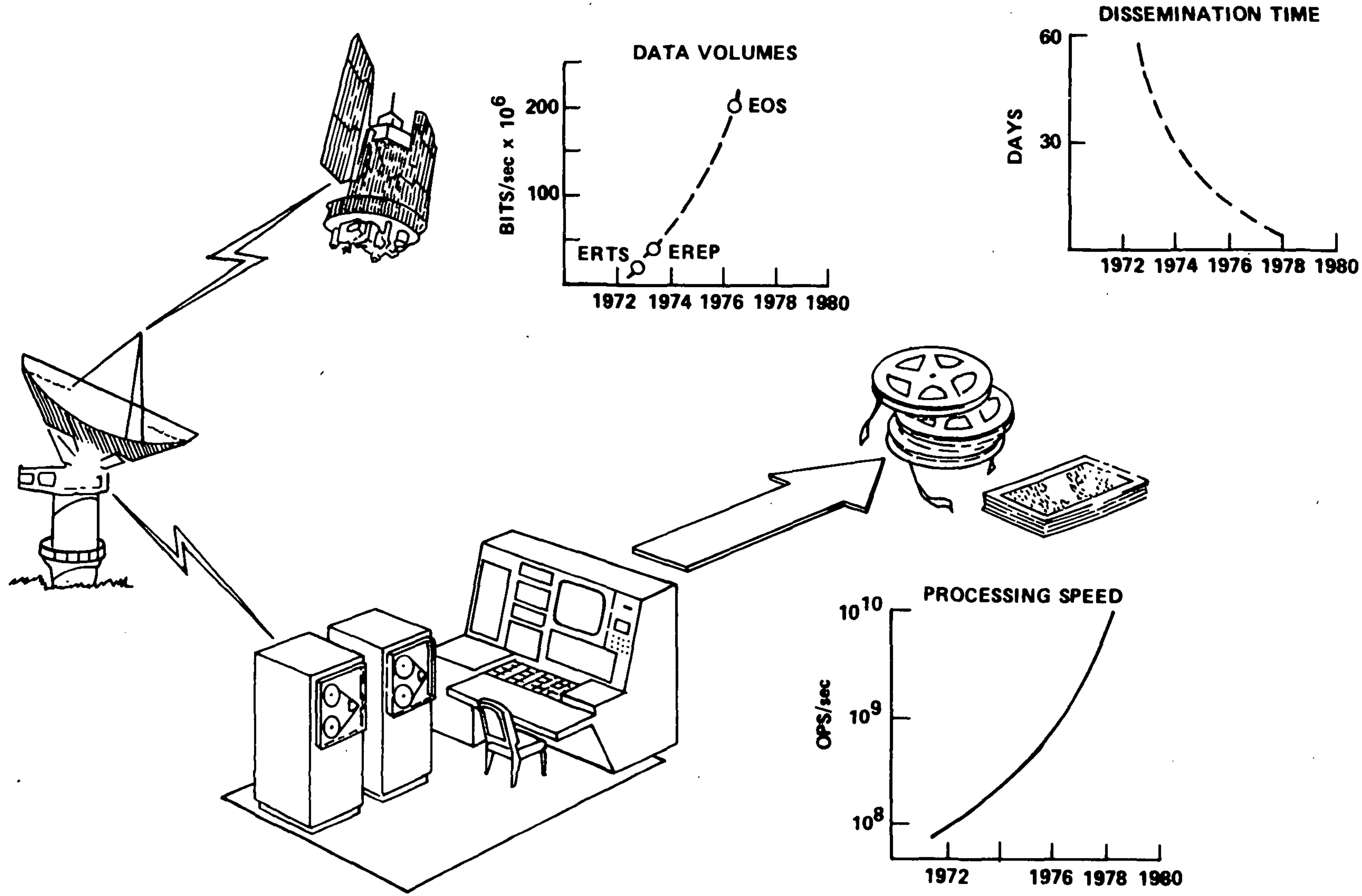

Figure III-20. Data handling and processing.

The experimental investigations of ERTS-1 have met their objectives and follow-on efforts will emphasize the demonstration of the ERTS system capability to perform quasi-operational applications.

(2) Earth Resources Experiment Package. The EREP of the Skylab mission series was the first manned and the second space earth resources survey system. As the name denotes, it was a set of experimental instruments which sought to evaluate the following:

- Man's role in space earth resources surveys
- Earth resources film return systems
- Applications of active and passive microwave systems
- High resolution photographic systems
- Narrow band multispectral scanning systems including near-, mid-, and thermal-infrared bands.

Final results of the experiments are not yet available; however, preliminary findings are encouraging. The sophisticated nature of the multisensor, multispectral data acquired in three missions during the 9-month activity period lends itself to computer processing and analysis. Many of the investigations are emphasizing machine-aided processing and classification techniques that will help define the improved systems of the future. Early Shuttle missions and the high spectral resolution systems of EOS will be based on the knowledge gained from EREP.

(3) Earth Observations Aircraft Project (EOAP). The earth resources program of today is based on the knowledge and experience gained in the EOAP. Beginning at Johnson Space Center (JSC) in 1965 with a twin-engined Convair 240 aircraft carrying surplus and loaned instruments, the project now includes light regional aircraft at five field centers, multiengine flying laboratories based at JSC and Ames, and high altitude U-2 and RB57F aircraft.

The primary purposes of the project aircraft are to provide testbeds for the development, test, and evaluation of remote sensing systems; provide high resolution, multispectral underflight data for the spacecraft flight project investigations; provide the primary data support for research and development of remote sensing techniques, systems, and exploratory investigations; and support other Federal agencies in the research and development of in-house investigations of specific applications.

Ames Research Center, where the Agency's U-2's and Convair 990 are based, is the lead center for coordinating and integrating the aircraft project. The aircraft have and are expected to continue to play an important role in the program. An aircraft/spacecraft mix is foreseen for future earth resources systems. In addition to their major R&D role, the aircraft are necessary for such tasks as the acquisition of high resolution statistical samples to correlate and complement spacecraft coverage, for quick-reaction coverage of transient phenomena occurring between spacecraft overflight, for all-weather acquisition until such capabilities are available on spacecraft, and for high resolution quick turnaround data acquisition requirements; e.g., disasters such as earthquakes, tornadoes, and hurricanes.

(4) Operational Systems. There are no operational earth resources systems today. The pace and direction of the program will be determined by the results of the ERTS-1 and EREP investigations in the six user application areas discussed previously. The Department of Interior is exploring the readiness of users to employ space-acquired data in their day-to-day resource management actions.

The earliest potential ERS operational system will be based on the technology and findings of ERTS. Such an operational system would have utility in land use monitoring, geological mapping, and surface water and vegetation inventory. Studies of potential improvements in the operational system include the use of multiple spacecraft to achieve a higher rate of data repeatability. Aircraft would be used to obtain highly repetitive data and high resolution data in selected areas. In situ platforms established at selected locations would make supporting measurements to be relayed in some instances by spacecraft.

The ERS Program is similar to the Weather and Climate Program in that a continuing R&D program is conducted from which operational systems would be derived periodically. The R&D program is based upon user requirements. Sensors are developed and flight tested, first on an aircraft and later on a spacecraft to determine their applicability. When the need for a certain type or class of user-oriented data is established, an operational system is proposed. The objectives identified earlier have many measurement requirements in common. This commonality leads to multipurpose space systems; i.e., use of data by several users for different applications. Planning is in progress to develop systems applicable to satisfying multiple objectives.

The future plans envision a continuing R& D program and operational systems dervied from it. The future R& D program will be an extension of the medium orbit effort initiated by the ERTS and Skylab programs and will be broadened to include development of remote sensing from geostationary altitude and on the Shuttle when that vehicle becomes available.

The ERS program will become operational when resource managers require and rely upon a continuous source of remotely sensed information for routine decision-making. A major NASA function is to define and demonstrate cost effective capabilities that allow user organizations to adapt the space remote sensing methodology. These demonstrations will be planned prior to availability of satellite data and conducted as early in the life of the satellite as possible.

Exploratory investigations such as those conducted with ERTS and EREP establish whether remote monitoring of a particular group of features is feasible or not (for a particular system). If the system proves feasible, operational methodology is to be developed, defining a demonstration project. If it proves not feasible, either the investigation is terminated or new instrumentation capabilities are explored for more advanced satellites.

Establishing feasibility from space data, developing operational methodology, and planning and conducting progressive demonstrations of remote sensing applications are the major thrusts and emphasis of the NASA Earth Resources Program.

4. PROGRAM FUNDING

Figure III-21 and Table III-3 depict the ERS program funding for FY-1972 to FY-1980. They show the funding breakdown for five categories of the program. These categories are as follows:

1. and 1.a Research — This effort is planned to be carried out at about $12.5 million per year through FY-1980. The increase shown in FY-1975 of approximately $10 million was assessed by NASA Field Centers, which formally received operations support funding from the Office of Manned Space Flight. This cost is an overhead charge which does not increase the amount of research effort that was being accomplished at the $12.5 million per year level.

2. Three large ASVT are planned for implementation in FY-1976 through FY-1978.

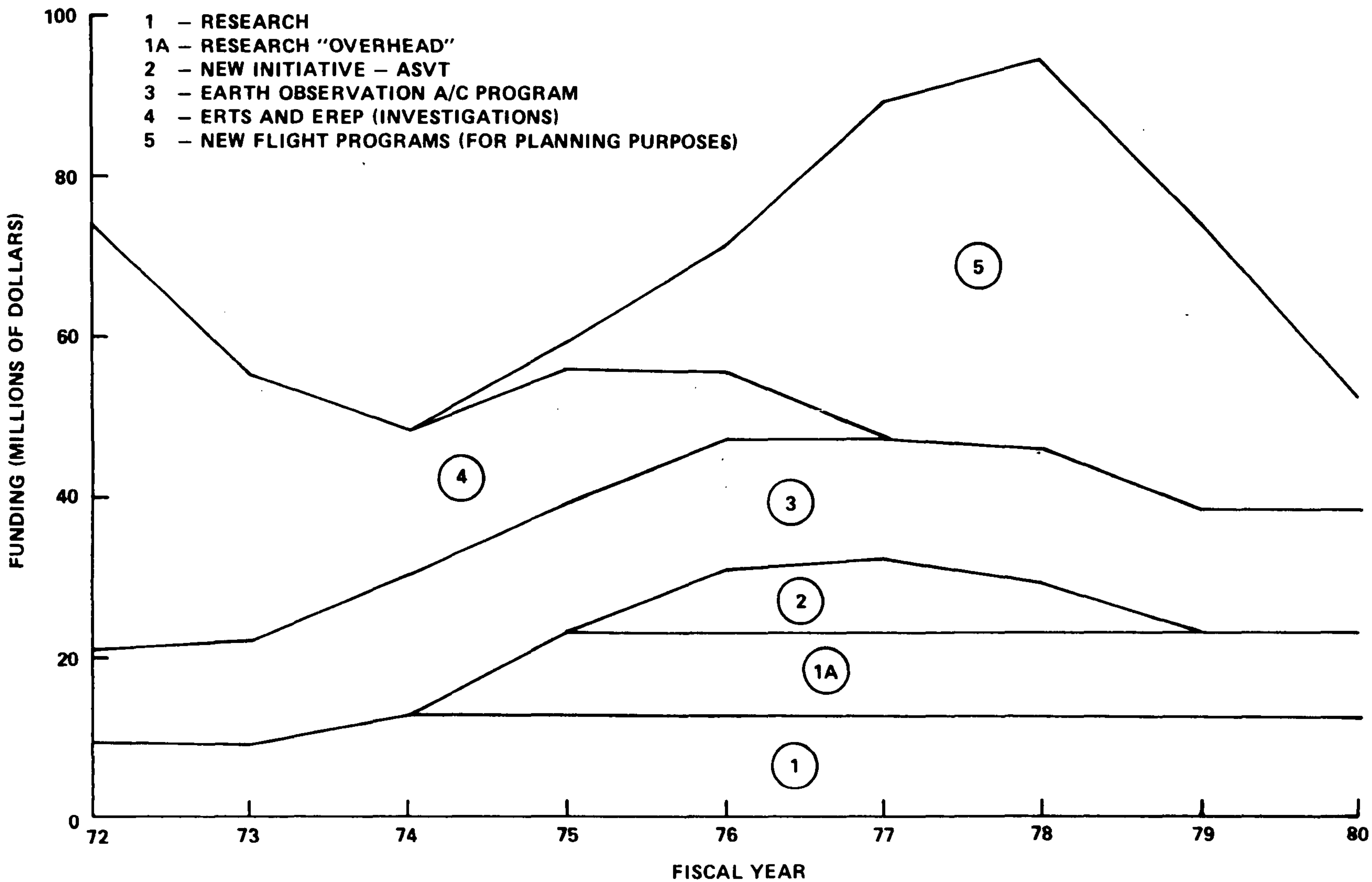

Figure III-21. Earth Resources Survey Program funding (millions of dollars versus fiscal year).

TABLE III-3. EARTH RESOURCES PROGRAM FUNDING HISTORY

	72	73	74	75	76	77	78	79	80
Research	9.9	9.6	13.2	22.4	22.4	22.4	22.4	22.4	22.4
New Initiative — ASVT					8.2	9.1	6.9		
Earth Observation Aircraft Program	12.4	13.0	16.8	17.3	16.4	16.4	16.4	16.4	16.4
ERTS and EREP (Investigations)	52.1	32.6	17.4	16.9	8.3				
New Flight Programs (For Planning Purposes)				2.5	15.5	41.0	49.1	35.5	14.1
Totals	74.4	55.2	47.4	59.1	70.8	88.9	94.8	74.3	52.9

3. The earth observations aircraft remote sensing program is planned to support the research activities at the $16.4 million level through 1980.

4. The Earth Resources Technology Satellite Program (ERTS-1 and -B) and the Skylab Earth Resources Experiment Package investigations are shown diminishing in FY-1977, after receiving heavy funding in the early development years.

5. New planned flight programs, which include a follow-on for ERTS and an earth resources mission for EOS, lead to a peak in FY-1978 of approximately $50 million and diminish thereafter.

5. COST BENEFIT STUDIES

The final measure of success will be whether or not operational systems are implemented. Decisions to undertake development and deployment of such systems must be based upon their cost as well as utility. Cost benefit ratios favorable to implementing operational systems could result from three situations: (a) the cost would be significantly less than the existing method for comparable results, (b) the system would significantly improve the degree of accomplishment at a comparable cost, or (c) the remote sensing offered the only practical method to meet a requirement.

Several studies have addressed the costs and potential benefits of space systems. In 1971, Interplan Corporation reviewed and appraised the results of ten earlier studies. Of the several hundred applications cited in the studies, benefit estimates for 85 applications were supported by sufficient discussion and documentation to be compared in a synoptic review. Those that were considered valid order-of-magnitude estimates totaled $1.4 billion, to be realized annually by the U.S. from implementation of 43 non-overlapping applications.

In 1973, Dynatrend, Incorporated, reviewed results of the ERTS-1 investigations to evaluate the extent to which the benefits identified in the Interplan Report could be achieved by an operational system of the ERTS-1 configuration. The intent of the study was to update the Interplan Report, based on the early results of ERTS-1, as collaborative justification for an operational system. It was concluded that an operational system configured to ERTS-1 would annually yield estimated benefits of $1 billion to the U.S. and approximately $7 billion to the remainder of the world.

These estimates are rough, order-of-magnitude values. Neither the Interplan Report nor the Dynatrend update attempted to conduct thorough systems or economic analyses. Such analyses are of increasing concern and major emphasis is being placed on ascertaining meaningful application cost benefit estimates from the experience and knowledge acquired with ERTS and EREP. Decisions regarding future systems and the pace of the program will be based to a large extent on the results.

Several studies are underway. In February 1973, the U.S. Department of Interior awarded a contract to the Earth Satellite Corporation for a comprehensive study of the use of satellite data for virtually all earth applications except communications/navigation and military surveillance activities. This study, to be conducted over an 18-month period ending in August 1974 is to correct many of the deficiencies of prior studies, including the summary provided by Interplan. Earth Satellite Corporation will conduct a thorough system analysis, identify potential users and action-chain mechanisms for data to be provided by an operational system, review all available relevant literature, conduct selected thorough field case studies with potential data users and decision-makers, and perform the necessary economic modeling and evaluation necessary to derive a comprehensive estimate of the costs and benefits associated with an operational system. The results of this study will be crucial to the decision to initiate the first Department of Interior operational system.

A Task Force on Economics of Remote Sensing has been established at NASA Headquarters to assess the cost/benefits and/or cost/effectiveness accruing from the use of remote sensing technology, with particular emphasis upon ERTS. One of the work tasks to be completed in this study is an assessment of the value of ERTS-B by Econ, Incorporated. Two basic questions are being addressed; the overall value of ERTS-B and the value of an October 1974 launch versus a January 1976 launch. Answers will sought as to the value of ERTS-B as a step toward the decision on an operational ERTS service system.

Analysis of potential applications with particular attention to cost-benefit aspects will receive major emphasis in the future. The importance of such information prior to initiation of new projects is paramount. Two major decision points require cost-benefit information. NASA must consider the economic aspects of potential applications prior to initiation of major demonstration/verification tests projects. This requires not only weighing system options to identify the most cost effective but an understanding of users' needs to have confidence that successful verification could result in user acceptance of the systems. The users need cost-benefit analysis

information on which to base decisions to implement the demonstrated remote sensing systems. Several studies are underway. A joint U.S. Department of Agriculture-NASA task force is gathering information regarding agricultural applications and the U.S. Department of Interior is conducting studies to define the first operational system. Results of these efforts will play a significant part in shaping the program in the last half of the 1970's.

6. INSTITUTIONAL ARRANGEMENTS

The Earth Resources Program is a multidiscipline, multifaceted effort serving a diverse group of users. In addition to the formally constituted Federal Government program participants, many state and local governments, industries, universities, and technical organizations are actively engaged in research, development, and operational activities. Although the majority of this non-Federal Government involvement is encouraged and supported by Federal contracts and grants, there is an uptrend in the use of private resources; e.g., state-sponsored resources surveys, internal industrial R&D, and no-cost ERTS and EREP investigations.

Some insight of the interrelationship of responsibilities and the interagency aspects of the program can be gained from the following data chain example. ERTS data are acquired and pre-processed by NASA and forwarded to the Department of Interior's Data Center at Sioux Falls, South Dakota. There the data are reproduced, cataloged, stored, and made available to various customers. The Department of Agriculture may obtain desired coverage and process it in correlation with other data to obtain information regarding crops. This information is distributed through local outlets, e.g., county agents, to farmers and other agricultural business decision-makers. Similar data chains are an integral part of most applications. It is apparent that some method of coordinating these efforts is necessary not only to effectively implement them but to do so in an efficient and economic manner. To this end the Interagency Coordination Committee for the Earth Resources Survey Program was established.

The ICCERSP is the primary executive branch mechanism for coordinating and integrating Federal Earth Resources Survey plans, policies, and programs. The charter issued by the Office of Management and Budget establishing the Committee defines its responsibilities and authority as: (a) coordination and integration of the Federal Earth Resources Survey Program; (b) coordination with related agency programs; (c) coordination outside the Federal Government; and (d) preparation of an annual Federal report and plan. (A copy of the ICCERSP charter is contained in the Appendices volume.)

The major Federal participants of the program include: NASA; the Departments of Agriculture, Commerce, and Interior; the Corps of Engineers (Civil Works); and the Environmental Protection Agency. The following paragraphs present brief summaries of the responsibilities and roles of these agencies within the national ERS program.

The Department of Agriculture (USDA) has broad responsibilities in the fields of forestry, soil, water, environmental, and other natural resource conservation; rural development, crop production adjustment, and farm price stabilization; consumer protection; agricultural research; education in agricultural developments and rural living in cooperation with state and local agencies; domestic and export marketing of agricultural products; domestic and foreign aid food distribution; foreign economic development; cooperative efforts with state agencies in economic research; and the dissemination of information about all aspects of agricultural programs, policies, and developments.

The objectives of USDA's participation in the experimental Earth Resources Survey Program are to (a) identify those particular applications where remote sensing could have a significant, beneficial impact on agriculture and related natural resources and (b) gather remotely sensed data applicable to extensive areas of publicly and privately managed lands which would permit identification of major agriculture crop types and forest species; insect damage, crop disease, soil salinity, and moisture differences; mapping of surface water, snowpack, and soil and water temperatures; and changes in land use.

The Department of Commerce (USDC), through the NOAA, is responsible for developing and executing programs to assure that the ocean environment and its resources are wisely used in a balanced way to enable their development as well as conservation for the national economic and environmental well being. NOAA is also charged with developing and operating systems to monitor and predict environmental conditions such as weather, ocean, earth, and solar events, and with exploring the feasibility of beneficial modification of environmental conditions and understanding the consequences of inadvertent environmental modification. NOAA produces aeronautical charts of the United States and its possessions and nautical charts of coastal waters and the Great Lakes. Through the Bureau of the Census, USDC is also responsible for providing a continuous statistical profile of the population of the Nation, measuring significant social and economic developments in each geographical area. Fulfilling these essential public functions requires a very large amount of data of many sorts over wide geographical areas, including global data in some cases.

In addition to attempting to meet its own mission objectives, USDC operates an ERS Data Center at Suitland, Maryland to meet the needs of secondary users, including the public, in its disciplinary areas.

Through a variety of programs, the mission of the Department of Interior (USDI) is to achieve efficient management of the natural resources of the Nation in appropriate balance with environmental quality objectives. USDI, through custody or trusteeship of a major portion of the Nation's resources, provides directly for their management and conservation. Through regulation, development assistance, research and research support, and the provision of information, USDI strongly influences modes and patterns of resource use not within its direct control.

USDI has established and EROS Data Center at Sioux Falls, South Dakota, for distribution to users and to the public of data obtained from satellites including ERTS, and from aircraft.

The Corps of Engineers of the United States Army (USACE) is responsible for the planning, design, construction, operation, and maintenance of civil works for improvement of rivers, harbors, and waterways for navigation, flood control, and other purposes, including shore protection. The USACE is also responsible for administering the laws for the protection and preservation of the navigable waters of the United States. The immediate objective of the USACE in remote sensing will be to evaluate the contribution of this field to water resources and marine science development as well as to emergency operations. A potential for useful applications of satellite and aircraft data exists in many areas such as the following: soil differentiation, topographic information, materials location, engineering geology, vegetation cover, water plant propagation and control, river migration and ice jamming, coastal engineering, estuary and inlet dynamics, hurricane, tsunami and other tidal surges, flood damage estimation and projection, snow cover and melt estimation, and disaster relief planning.

NASA has broad responsibility for the development of space and aircraft technology for peaceful and beneficial applications, including the necessary research and development to demonstrate the practical nature and usefulness of such applications.

In cooperation with Government agencies and other organizations, NASA conducts a broad program of applying space technology to Earth Resources Surveys. The work includes the development of procedures, instruments, subsystems, spacecraft, and interpretative techniques for the purpose of

increasing basic knowledge of the earth's atmosphere, land areas, and oceans, as well as man's effect on these resources. The data so obtained benefit those concerned with mineral and land resources, land use, water resources, marine resources, agriculture, forestry and range lands, the earth's environment, and mapping and charting.

Three goals have been established: (a) to develop the capability for remote sensing of the earth from aircraft and spacecraft; (b) to develop experimental and operational applications of ERS technology to meet user requirements; and (c) to develop methods for handling large quantities of remotely sensed data, including the transmission, reduction, processing, storage and retrieval, and dissemination of the data.

Within NASA, management of the program is the responsibility of the Earth Observations Programs Office (ER), Office of Applications, at NASA Headquarters. ER is responsible for all NASA remote sensing activities involving earth resources, weather and climate, and environmental quality and is aided by lead centers. The Johnson Space Center is lead center for earth resources providing program coordination, integration, planning, and review. All the NASA centers are actively engaged in carrying out the program.

To provide internal NASA program coordination and to serve as a forum for program coordination, discussion, and communication with NASA institutional management, the Applications Program Integration Board (APIB) has been established. Membership includes all center directors who serve in an advisory capability to the Associate Administrator for Applications.

At the lead Center (JSC), an earth Resources Program Integration Board (ERPIB) has been established as a group that functions to advise the lead center program manager. Standing discipline panels have been established to advise the lead center on matters concerning the applications disciplines; i.e., review of ERTS and EREP investigations results, evaluation of ERTS follow-on investigations proposals, discipline assessments, etc.

International cooperation in earth resources remote sensing was initiated by the U.S. primarily to establish the bona fide and the open, peaceful character of the research program on which NASA and user agencies were embarking, and to provide research data from outside the U.S. useful in the development of earth resources survey techniques with worldwide applicability.

These initiatives have followed the lines indicated by President Nixon in his September 18, 1969, address to the United Nations General Assembly in which he said, in part, "I feel it is only right that we should share both the adventures and the benefits of space. As an example of our plans, we have determined to take actions with regard to earth resources satellites as this program proceeds and fulfills its promise. . . The purpose of those actions is that this program will be dedicated to produce information not only for the United States but also for the world community."

The earliest cooperative ERS projects were with Brazil and Mexico and were based upon aircraft remote sensing techniques. These two countries were chosen because of previous cooperative space efforts with the United States. One of the purposes of this effort was to help establish pilot projects whose frames of reference and character would be meaningful to other developing countries. The results have been encouraging.

In other cooperative efforts, the United States has provided assistance to the Indian Space Research Organization in acquiring remote sensing data over areas of coconut palm blight in the state of Kerala. At the request of the Peruvian Government, the NASA P3A remote sensing aircraft acquired data over the severely earthquake-damaged areas of Peru in July 1970 to assist with its damage assessment effort and to acquire data useful for the development of the ERS program. In December 1972, a NASA C130 aircraft performed a similar mission following the earthquake at Managua, Nicaragua. The United Nations Food and Agriculture Organization and the Jamaican government worked with U.S. scientists in acquiring and analyzing data of Jamaica in a demonstration project to study hydrologic and other applications of remote sensing data. The U.S. Government sponsored an International Workshop on Earth Resources Survey Systems in May 1971 at the University of Michigan. Representatives of 42 countries and 16 international organizations attended.

A cooperative atmosphere was developed during these early efforts and continues today in the ERTS and EREP investigations. Table III-4 illustrates the international scope of these missions where some 39 countries are investigating applications of mutual interest.

TABLE III-4. SKYLAB EREP/ERTS-1 INTERNATIONAL INVESTIGATIONS

Country	EREP	ERTS-1	Country	EREP	ERTS-1
Argentina	4	4	Iran	2	1
Australia	1	2	Israel	6	1
Bangladesh		1	Italy	2	3
Belgium		3	Japan	4	4
Bolivia		1	Kenya		1
Botswana		1	Korea		1
Brazil	7	5	Lesotho		1
Canada	3	8	Mali	1	1
Chile	1	2	Mexico		10
Columbia		3	Netherlands	1	3
Ecuador		1	Norway		5
England	2	5	Peru		1
F.A.O. (UN)	2		Phillippines		1
Finland		3	South Africa		2
France	2	15	Spain		3
Germany	7	6	Sweden		2
Greece	3	2	Switzerland	1	1
Guatemala		1	Thailand	1	2
India	1	1	Venezuela	3	2
Indonesia		2			
		Totals	39	54	111

C. Environmental Quality Program

1. HISTORY

Over the past few years, concern with the environment has matured from what might have been called a "fad" to an important fact of life. Environmental quality has become one of many important but often competing national goals. With maturity has come the recognition that we must be as aware of the impact of control and elimination of pollution as we are of the results of neglect. The balance that must be struck between relaxing emission standards and limiting supplies is a difficult one and such decisions cannot be made without adequate information. Pollution monitoring provides part of the information necessary to make these decisions.

The potential benefits to be derived from the application of space technology to pollution monitoring are generally well recognized. In the fall of 1966, NASA asked the National Academy of Science to conduct a study [1] on "the probable usefulness of satellites in practical Earth-oriented applications." Technical panels consisting of highly qualified scientists and engineers were convened to study the many aspects of space applications and to make recommendations as to the nature and scope of research and development programs needed to provide the technology required to exploit these applications.

With regard to air pollution, the Meteorology Panel recommended "...that NASA encourage and support a ground-based research-and-development program in high-resolution spectroscopy of polluted air, to evaluate possibility and merit of detecting and monitoring atmospheric pollutants from satellites."

Massachusetts Institute of Technology sponsored a Study of Critical Environmental Problems (SCEP) [2] in 1970 in preparation for the 1972 United Nations Conference on the Human Environment. The SCEP Work Group on Monitoring recommended "...a series of evaluations of appropriate satellite measurement and monitoring techniques, including both scientific feasibility studies and cost-benefits analyses, aimed at determining the role of satellites in an optimum monitoring system for the problems dealt with by SCEP."

Subsequent to SCEP, NASA sponsored an ad hoc working group to investigate in detail the role of remote sensing in identifying and/or monitoring specific contaminants. This group met for 1 week in August 1971, to complete a report [3] on the measurement requirements and state-of-the-art of remote

measurement techniques for gaseous and particulate air pollution and water pollution. The resulting document entitled "Remote Measurement of Pollution" has since served as a cornerstone for the planning and implementation of NASA's environmental quality monitoring program.

The report summarizes the state-of-the-art of remote sensing of pollutants in the following way: "Thus, it becomes evident from the panel reports that many of the trace gases that concern us are amenable to remote sensing; that certain water pollutants can be measured by remote techniques, but their number is limited; and that a similar approach to the remote measurement of specific particulate pollutants will follow only after our understanding of their physical, chemical, and radiative properties is improved. It is also clear from the reports that remote sensing can provide us with essential information in all three categories that can not be obtained by any other means."

The task of monitoring the environment is complex, and no one approach or method can provide all the information we need. There are some instances in which only point sampling methods will suffice. Yet such methods are totally impractical for large scale regional or global problems. It is also the very nature of the pollution, and indeed of the environment itself, that it is a dynamic process which we must manage. Local problems seldom remain local problems. The demand for the larger view, or overview, is increasing, and with it comes the further need that this view be both qualitative and quantitative. For NASA this has meant that its space technology, especially remote sensing technology, must be addressed to this significant area of applications.

Remote sensing, especially from aircraft and spacecraft, is advantageous in environmental studies because it provides simultaneous measurements over large areas at a time. These measurements also have a builtin consistency that comes from using the same instrument for all measurements instead of a large network of sensors of possibly varying accuracy. Remote sensors are also important in ground-based application, particularly where accessibility may be a problem. Remote sensing technology applicable to sensing of the environment has been developed throughout the years of NASA's existence in support of the meteorology and earth resources programs.

In 1973, for the first time, pollution monitoring was established as a new discipline in the programs of the Office of Applications. Significant sensor development efforts were identified in this area, and the Nimbus G mission represented a new initiative with its prime emphasis on assessing the utility of this technology for detecting and monitoring pollution from space.

NASA's support of environmental agencies, at Federal, state, and local levels, takes place in a variety of ways, ranging from response to direct requests for support on particular tasks to joint exploration of technology feasibility in applications demonstration and verification tests. Mutual exchanges of information on current research are becoming increasingly effective in developing ways to improve this support.

The nature of NASA support for environmental agencies is illustrated by the summary of existing interagency agreements with the Environmental Protection Agency (EPA) given in Table III-5.

The first two activities listed in the table deal with environmental problems related to engine technology; the remainder of the activies deal in one way or another with sensor technology. The working agreements covering these activities vary from formal interagency agreements negotiated at the higher levels of management to informal agreements between groups in the two agencies with mutual technical interest in a particular environmental problem.

2. GOALS AND OBJECTIVES

The overall goal of the pollution monitoring program is to demonstrate the ability of remote sensing systems to detect and quantify pollution on a local, regional, national, and global scale. NASA has a continuing program of technology development for pollution monitoring that covers a wide range of scientific and engineering disciplines. All aspects of environmental quality are of interest including air, water, and land pollution. However, air quality represents the most advanced area of the program, largely because of inheritance from the long established meteorological program. Although pollution monitoring has now evolved into a separate discipline, the interface with meteorology will remain strong.

The following is a summary of specific objectives in the pollution monitoring program for air, water, and land:

a. Air

- Evaluate the role of remote sensing in monitoring urban air quality.

- Determine pollutant burdens in the troposphere on a regional and national scale.

TABLE III-5. SUMMARY OF EXISTING NASA/EPA AGREEMENTS

Organizational Unit — NASA/EPA	Nature of Agreement
Lewis Research Center (LeRC)/Office of Air and Water Programs	Development of automotive gas turbine technology — LeRC will upgrade an EPA-selected gas turbine engine to meet EPA's end objectives.
Office of Aeronautics and Space Technology/Office of Categorical Problems	Aircraft noise abatement and control project includes new front-fan jet engine retrofit activity, quiet engine and V-STOL programs, and community noise evaluation near airports.
Goddard Space Flight Center/Office of Enforcement and General Counsel	Use of ERTS imagery in support of compliance and care preparation investigations.
Langley Research Center/Office of Research and Development	Test and evaluation of water quality sensors.
Wallops Station/Office of Research and Development	Experiments with a laser system of chlorophyll-bearing organisms in water.
Lewis Research Center/National Environmental Research Center (NERC) — Research Triangle Park	Development of techniques to measure trace amounts of materials in fuel samples.
Lewis Research Center/NERC — Cincinnati	Development of automated contact sensors for detecting water pollution — sensors will be used with data collection system on Nimbus.
Langley Research Center/NERC — Research Triangle Park	Development of sensors for detecting particles and gases in stack emissions.
Lewis Research Center/EPA — Region V	Development of an environmental monitoring system for the Great Lakes Basin.
Ames Research Center (ARC)/NERC — Las Vegas	EPS use of an ARC differential radiometer system to detect chlorophyll concentrations in water.
Ames Research Center/NERC — Corvallis	EPA use of NASA RB-57 photography to help study lake drainage and land use.

- Measure stratospheric trace constituents potentially affecting climate and health.

- Develop systems for assessing the impact of atmospheric quality control strategies on a global scale.

b. Water

- Develop remote sensing techniques for detection and monitoring substances affecting water quality such as oil seeps, spills, and slicks; chemical toxic waste; nutrient wastes; thermal effluents; and suspended sediments.

- Develop remote sensing techniques for detection and monitoring of processes affecting water quality such as water eutrophication, salt water incursion, and urban hydrology.

c. Land

- Develop remote sensing techniques for detection, location, and monitoring of those land use practices that contribute significantly to the degradation of environmental quality; i.e., the sources of pollution.

3. IMPLEMENTATION

NASA's program of technology development for pollution monitoring covers a wide spectrum of activities from fundamental studies of the physical processes involved in environmental pollution, through the development of modeling and monitoring techniques, to the demonstration of technological advancements by appropriate aircraft and satellite missions. The following is a summary of these activities divided into the disciplines of air, water, and land pollution monitoring.

a. Air Quality

(1) Fundamental studies. Developing the capability for measuring pollutants or trace gases in the atmosphere must begin with an understanding of what can be measured and how to do it most effectively. In emphasizing remote sensing we are generally concentrating on measuring the scattering absorption and emission of electromagnetic radiation, from microwave wavelengths through the visible spectrum and into the ultraviolet. Substantial analytic and experimental studies of these interactions, of a somewhat fundamental nature, must precede both the development of sensors and tests of their suitability for operational use in environmental monitoring.

Work currently under way includes the detailed measurement of spectra in regions considered suitable for sensor applications. This includes spectra of oxygen, ozone, ammonia, and sulphur dioxide. In addition, theoretical models of spectra for such pollutants as sulphur dioxide and nitric acid are also under development.

(2) Sensor Development. The sensor development program for air pollution sensing is built on the fundamental studies and the instrumentation technology of the meteorological satellite program. However, the relatively simple radiometers and spectrometers used in previous satellite programs are going to be replaced by more sophisticated instruments of greater selectivity, sensitivity, and capacity.

A number of air pollution remote sensors have been or are currently being developed under the AAFE program. The AAFE program is an Office of Applications program intended to establish candidate experiments for future applications missions. The program consists of the engineering development and demonstration of promising applications experiments, beginning with the existence of a feasible concept from SR&T investigations and extending to an interface with flight concept prototype development. The AAFE program supports experiment and sensor development in all applications areas including communications, weather and climate, ocean dynamics monitoring, earth resources survey, navigation, and traffic control as well as pollution monitoring. Table III-6 summarizes the features of a number of the air quality remote sensing instruments and experiments currently under development. All of the experiments listed in Table III-6 have been funded under the AAFE program with the exception of the LIDAR experiment, which is currently in the SR&T stage of development.

(3) Modeling. In parallel with the sensor development and test efforts, whose intent is to measure the environment, NASA supports a strong program in environmental modeling. These models are mathematical descriptions of the manner in which pollutants are dispersed in the atmosphere and the manner in which they interact with each other. The models serve many functions such as defining requirements for future sensor coverage and sensitivity, interpreting available sensor measurements, and providing a theoretical framework in which variations in the atmosphere and pollutant concentrations can be studied. Eventually, these models, fed by adequate baseline data, can help predict the future state of the environment.

TABLE III-6. NASA AIR QUALITY REMOTE SENSING INSTRUMENTS AND EXPERIMENTS

Experiment Title (NASA Center)	Measurement Capability	Instrument Features	Modeling and Data Interpretation
LACATE — Lower Atmosphere Composition and Temperature Experiment (Langley)	Vertical profiles of trace gases (O_3, HNO_3, N_2O, H_2O, CH_4, NO_2) Temperature profile in lower stratosphere	Infrared limb-scanned radiometer Large telescope Cooled detector	Inversion of radiance values to constituent profiles
MAPS — Monitoring Air Pollution from a Satellite (Langley)	Column densities of trace gases (SO_2, NO_2, NH_3, CH_4, CO_2, CO)	Infrared radiometer Gas-filter correlation analyzer Cooled detector	Inversion of radiance values to constituent burdens
RPM — Visible Radiation Polarization Measurements (Langley)	Polarization characteristics of scattered sunlight Characteristics of aerosols (by inference)	Photopolarimeter	Modeling and data interpretation is challenging task
HSI — High Speed Interferometer (Jet Propulsion Laboratory)	Absorption spectra of selected trace gases	Infrared interferometer spectrometer High resolution with high speed scan	Experiment requires transmission and sophisticated processing of large amounts of data
COPE — Carbon-Monoxide Pollution Experiment (Langley)	Column densities of trace gases — CO, CH_4,	Near infrared Correlation interferometer	Inversion of radiance values to constituent burden
Multi-Pollutant Version of COPE Instrument (Langley)	Column densities of trace gases — CO, CH_4, SO_2, NO_x	Infrared Correlation interferometer	Present SRT effort limited to preliminary design study of experiment requirements
Tunable Laser Heterodyne Radiometer (Langley, JPL)	Improve sensor specificity and sensitivity	Visible, infrared Improved front end for spectral radiometers	Present SRT effort limited to experimental feasibility study for SO_2, NO_x
LIDAR — Multiple Wavelength Laser Radar (Langley)	Aerosols and trace gases	Steerable 48 inch and 24 inch for ground-based laser radar	Theoretical and experimental laboratory studies of scattering characteristics of aerosols and trace gases

Modeling of pollutant transport, like monitoring, must be carried out at all scales: local, urban, regional, and global. Current investigations of the effluents from representative launch vehicles are an excellent example of research at the local scale. Modeling on the urban and regional scales are the prime responsibility of agencies such as the EPA and NOAA, but NASA has begun support efforts to improve existing models with more detailed treatments of fluid mechanical processes such as mixing and also with more accurate mathematical descriptions of topography. Generalized models are being developed to study the sensitivity of predictions to descriptions of effects such as chemistry and scavenging which are not generally treated in available urban models. Cognizance with and by EPA is maintained to avoid duplication of effort.

Modeling at the regional scale involves the linking of meteorological and pollution source data from several complex urban sources. NASA is developing methods and generalized models to facilitate the transfer of data between models at all scales from local to global. At regional scales the need for the synoptic data that satellites can provide becomes evident. The Nimbus-G mission is a first step in this direction although instruments needed to produce the kind of resolution needed for regional models is still under development. Support of the San Francisco Bay area model being developed by Livermore Radiation Laboratory and also cooperation with EPA in developing a Las Vegas pollution model are notable in that they are already being keyed to the use of satellite meteorological data.

Finally, at the global scale, NASA is supporting the Department of Transportation (DOT) Climatic Impact Assessment Program (CIAP) to assess the global effects of aircraft operations in the stratosphere. This activity, like the launch effluent modeling at the local scale is a direct responsibility under NASA's charter.

NASA is placing considerable emphasis on developing global pollution models of the stratosphere. A one-dimensional model which includes mass and radiation transport, diffusion, and detailed chemistry is now operating. A two-dimensional model with simplified chemistry will be operational shortly and plans are being made for development of a three-dimensional model that will take full advantage of the advanced computational capability provided by an advanced computer system. Some time in the future, general circulation models will be added to create a global pollution model of the stratosphere.

Determining the distributions and types of particulates in the atmosphere promises to present measurement problems as difficult as they are important, because particulates play a significant role in the chemistry of the atmosphere and the earth's energy budget, which is the ultimate determinant of climate. We are increasing our efforts to develop ways of reliably measuring the earth's albedo and changes in it.

b. Water Quality. NASA's water quality sensing programs are in an earlier state of development than those of air, largely because of presently inadequate knowledge of the spectral absorption and reflection characteristics of pollutants in water. Some natural pollutants (such as sediment) were among the first to be observed from space, in early Gemini and Apollo photographs. Today, remote measurement capabilities extend to state variables, such as temperature and salinity, and indirect but highly sensitive water quality indicators such as chlorophyll, as well as localized infusions of foreign materials such as oil. Since water does selectively absorb solar radiation, the reflected and scattered energy available for remote sensing is primarily from surface or near-surface effects. Work in the coming and future years is planned to expand our knowledge of the spectra of waterborne pollutants, within and outside the visible spectrum, and to make increasing use of active sensing techniques.

One important water quality indicator is chlorophyll content. Continuing chlorophyll detection studies will include support of the EPA Lake Eutrophication Program using ERTS-1 photos and active (laser) systems to increase measurement specificity. A four-color laser system, flight tested in cooperation with the Virginia Institute of Marine Science and Old Dominion University, has demonstrated the capability of distinguishing four classes of algae based on the chlorophyll fluorescent response of the algae to the different colors of the laser radiation. Continuing work with EPA will explore the system's feasibility for operational EPA use.

Turning to manmade water pollutants, oil spills remain one of our prominent ecological problems and promise to remain so until other sources of energy are developed. Reliable spill detection, permitting early and effective cleanup, is one of the key factors in avoiding environmental damage. A joint program with the Coast Guard has shown the effectiveness of an aircraft mounted wideband TV system with appropriate color and polarization filters for detecting spills with far greater clarity than the unaided eye. Research will continue to explore the feasibility of night detection, to provide for larger fields of view and to compensate for sunglint, all of which are features needed for an operational system.

The microwave wavelengths have been shown to be an effective spectral region for oil detection because of the very different effective brightness temperatures of oil and water. Tests with a dual frequency microwave radiometer supplied by the Naval Research Laboratory indicate the possibility of day/night detection of oil spills with 10-percent accuracy in spill volume estimation. Use of an improved scanning radiometer in the coming years will be a further step in developing a system with more of the features required in an operational system. Active systems using a laser to excite fluorescence in the oil are also being developed.

Establishment of an effective pollution monitoring and control system requires not only the ability to find pollutants, i.e., to sense their presence, but also an understanding of where they go once deposited in the water. NASA is looking at dispersal problems in two ways, by developing trackable buoys for experiments to chart current drifts and through flow modeling of the continental shelf and ocean waters. Radio transmitter, radar transponder, and satellite interrogated buoys have been developed and successfully used to chart currents at various depths. A number of cooperative programs notably with NOAA, National Center for Atmospheric Research (NCAR, Woods Hole Oceanographic Institute, Virginia Institute of Marine Sciences (VIMS) and others have charted post-hurricane fresh water flow in the Chesapeake Bay, nutrient flow through barrier islands of the Virginia Eastern Shore, and currents involved in offshore sand ridge formation. Future research directions include possible development of an air-launched buoy that would greatly facilitate deployment. These studies provide valuable basic data not only for operational agencies but also for inputs to the development of analytic models of coastal zone and oceanic circulations.

Ocean circulation models have been developed at various scales — global, ocean basin, and continental shelf — and linked together in the manner described for atmospheric models. A prime goal of future research is to improve the transition between scales and to incorporate realistic boundary conditions, such as irregular shorelines necessary to evaluate the impact of proposed offshore ports and power stations.

Studies of inland waters are progressing with a Lake Erie circulation model that can now accurately model behavior for 3 of the 4 seasons of the year (summer surface heating inhibits normal circulation). In cooperation with EPA, the Corps of Engineers and others, cooperation which will result in a complete lake pollution model, this effort will not only improve understanding of lake processes but will also help define the sensor locations and sensitivities required for effective monitoring and control.

c. Land Pollution. Definition of land pollution problems is in its infancy. Much work in this area, such as development of land use evaluation technology, is and will continue to be done through the earth resources program. Misuse of the nation's land through unreclaimed strip-mining, poorly planned denudation of forested land, and the like degrade our environment as surely as a belching smokestack or an untreated sewage outfall. The ERTS program has created a national capability for land use planning. Computerized land use classification techniques are widely available, and through our earth resources and user affairs programs, NASA is making contact with urban, state and regional planners to transfer this technology as effectively as possible.

However, in addition to pollution by land misuse, the land often serves as a source of air and water pollutants. Forest fires, severe storms, and surface winds over bare land inject significant amounts of particulates into the atmosphere. Natural biological processes in forests, swamps, and waterways release hydrogen sulfide, methane, ammonia, and other potentially harmful trace constituents into the air. The nation's waters are clouded by silt and chemically changed by seepage from limestone aquifers and acid drainage from abandoned mines. Conversely, the land collects pollutants scavenged from the atmosphere by rain or chemical reactions frequently passing them, in turn, to our streams, lakes, and oceans as ultimate pollutants of our waters.

Initial studies of the role of land in pollution of the environment are concentrating on a few selected problems such as acid mine drainage and river basin control. In the coming years, studies will be iniated to define present capabilities and to explore ways of optimizing sensor ranges and data processing techniques for land-oriented pollution problems.

d. Aircraft Programs. NASA has utilized aircraft extensively in numerous environmental quality programs. The Earth Observations Aircraft Program was established in 1964 at NASA's Johnson Space Center to develop earth survey techniques using aircraft equipped with various combinations of photographic, infrared, and microwave remote sensing instruments. The development of techniques for land and water pollution monitoring has been an important element of this program. Other programs are devoted to in situ measurements on a global scale from commercial aircraft and high altitude investigations of stratospheric pollutants from a U2 aircraft and the British and French Concorde prototypes. Current plans include the development of an aircraft program to demonstrate the capability of a remote monitoring system for local and regional environmental quality. This program will concentrate on the application of NASA developed technology to specific environmental monitoring problems. The initial phase of the program will concentrate on developing a system to assess urban air quality.

e. Stratopheric Aerosol Measurement Experiment for the Apollo-Soyuz Test Project. The Apollo-Soyuz Test Project (ASTP) to be launched in 1975 is the only manned space venture scheduled before the advent of the Space Shuttle. This joint U.S./U.S.S.R. project will have a number of space applications experiments including one devoted to demonstrating the feasibility of remote sensing or stratospheric aerosols. The sensor selected for this experiment is a photometer which will point at the sun during sunrise and sunset as viewed from the spacecraft. It is a precursor experiment for the Nimbus-G mission.

f. Nimbus-G. In the past NASA's earth applications satellites have concentrated primarily on meteorology, communications, and earth resource surveys. The Nimbus-G mission is the first satellite designed to study the problems of atmospheric pollution in a comprehensive manner. The prime mission objectives are twofold: (1) to measure the types, quantities, and distributions of gases and particulates in the troposphere and in the stratosphere and (2) to measure the color, temperature, and ice conditions of the ocean. In support of these objectives, other experiments will study the interface of the atmosphere with the oceans and land, and the earth's energy budget.

This experimental mission will provide repetitive, synoptic global views for many environmental parameters for the first time. Operating from a nearly polar, sun synchronous orbit, Nimbus-G will view the earth at the same local sun time everywhere, providing the same type of viewing comparability that has been so advantageous in the ERTS-1 mission.

The instrument complement for the Nimbus G is summarized in Table III-7.

g. Environmental Quality Missions Beyond Nimbus-G. A number of pollution monitoring satellites beyond Nimbus-G are currently under study. These studies include follow-on missions to Nimbus-G which exploit advances in pollution sensing technology, missions requiring specialized orbits other than Nimbus-G, and missions utilizing the unique capabilities of the Space Shuttle. Some specific objectives for pollution monitoring missions beyond Nimbus-G are as follows:

(1) To measure additional pollutants and employ additional promising techniques in the support of the national goal of developing an operational pollution monitoring system.

(2) To make measurements with sufficient spatial resolution to address national or large regional problems as well as global scale problems.

TABLE III-7. NIMBUS-G INSTRUMENT SUMMARY

Instrument	Type Device	Parameters Measured
LACATE – Lower Atmospheric Composition and Temperature Experiment	Limb Scanning Infrared Radiometer	O_3, NO_2, H_2O, HNO_3, N_2O, CH_4, Aerosols, Temperature – Vertical Profiles
MAPS – Measurement of Air Pollution from Satellites	Earth Pointing Gas Filter Infrared Radiometer	CO, SO_2, CH_4, NH_3 – Vertical Burden
SAMS – Stratospheric and Mesospheric Sounder	Limb Scanning Pressure Modulated Infrared Radiometer	CO_2, H_2O, CH_4, NO, N_2O, NO_2, CO, Temperature – Vertical Profiles
SAM-II – Stratospheric Aerosol Measurement	Solar Extinction Photometer	Aerosols – Vertical Profiles
BUV/TOMS – Backscatter Ultraviolet/Total Ozone Mapping Spectrometer	Sun and Earth Viewing Radiometer	O_3, Backscattered Ultraviolet Radiation
ERB – Earth Radiation Budget	Sun and Earth Viewing Spectrometer	Solar Radiation and Earth Reflected Short Wave and Emitted Longwave Radiation
SMMR – Scanning Multispectral Microwave Radiometer	Earth Viewing Microwave Radiometer	Sea Ice, Sea Surface Winds, Snow Cover, Soil Moisture, Storm Structure, and Water Content
SSTIR – Sea Surface Temperature Infrared Radiometer	Earth Viewing Infrared Radiometer	Ocean Surface Temperature Better Than 1°K
CZCS – Coastal Zone Color Scanner	Earth Viewing Radiometer	Chlorophyll, Sediment Distribution, Salinity, Temperature, Currents

(3) To extend the stratospheric measurements in the time domain to include diurnal sampling and multiyear duration missions.

(4) To extend the tropospheric measurements to sensing pollutant concentrations nearer the surface of the earth and to supplement total burden measurements with vertical distribution data.

(5) To extend the aerosol measurements to include more information on aerosol optical properties.

(6) To make an initial correlation of earth radiative budget parameters with pollutant stresses.

(7) To make measurements of the continental water quality, concentrating on the coastal zones, the Great Lakes, and the larger estuarine systems.

(8) To observe with improved resolution the effects of pollution on land.

Possible experiments for Nimbus-G follow-on missions are summarized in Table III-8.

Current planning activities are directed toward the requirements for pollution monitoring missions requiring multiple sensors and hence the capabilities of Nimbus or EOS class satellites. Planning is also underway for small, Small Applications Technology Satellite (SATS) class environmental quality monitoring satellites requiring specialized orbits. An example of this class of mission is a mission to monitor stratospheric aerosols by solar occultation in an orbit designed to obtain maximum longitudinal coverage and maximum frequency of coverage.

Space Shuttle capabilities in the 1980's will add a new dimension to space operations. In pollution monitoring, as in other disciplines, it will provide the capability for larger payloads for automated spacecraft. The Spacelab will provide a means of testing sensors in space early in the development cycle thus shortening lead times and reducing development cost. Estimated schedules for environmental quality monitoring missions are summarized in Figure III-22.

h. Funding Summary. Office of Applications funding for pollution monitoring programs is distributed primarily in the SR&T program, the AAFE program, and flight projects. Funding for the SR&T program amounted to $960,000 in FY-73 and $1,400 in FY-74. The anticipated funding for the pollution monitoring experiments currently under development in the AAFE program amounts to approximately $5,300,000. The ASTP and Nimbus-G are the only currently approved satellite missions carrying pollution monitoring instruments. The cost of the aerosol measuring photometer for the ASTP mission has been budgeted at $400,000. The total budget for the Nimbus-G project is between $75 and $80 million including investigator's cost. Of this amount, approximately $24 million will be devoted to instrument cost, with well over half of the instrument cost going to the pollution monitoring experiments.

TABLE III-8. ADVANCED POLLUTION MONITORING MISSION EXPERIMENTS

Experiment Type	Measurand	Desirable Experiment Capabilities	Specific Objective Supported
1. Stratospheric Sounding	Trace Gases (O_3, H_2O, HNO_3, N_2O, CH_4, CO_2 NO)	Vertical Profiles (Limb Scanning) Diurnal Variations Global Coverage	(1), (3)
2. Tropospheric Sounding	Trace Gases (CO, CH_4, NH_3, H_2O, CH_2O, HCl, SO_2, NO_2, some <HC>)	Measurements to Surface (Nadir View) Vertical Distribution 10 to 40 km Spatial Resolution Regional Coverage	(1), (2), (4)
3. Atmospheric Aerosol Sounding	Aerosol Properties (Size and Shape Distributions, Composition, Index of Refraction)	Optical Characteristics of Aerosols Inferred Stratospheric and Tropospheric Coverage Global and Regional Coverage	(1), (5)
4. Continental Water Quality Sensing	Organic Matter Sediment Oil Water Pollutants	Color Mapping Fluoresence/Luminescence Detection	(1), (2), (7)
5. Ocean Characteristics Sensing	Organic Matter Temperature Oil Spills	Color Mapping IR Thermal Mapping Microwave Signatures	(1)
6. Land Pollution Sensing	Pollution Effects Land Abuses Land Reclamation	High Resolution Imagery Thermatic Mapping	(8)
7. Radiation Observations	Earth Albedo and Emitted Radiation Cloud Images	Correlation of Data with Atmospheric Pollution Measurements	(6)

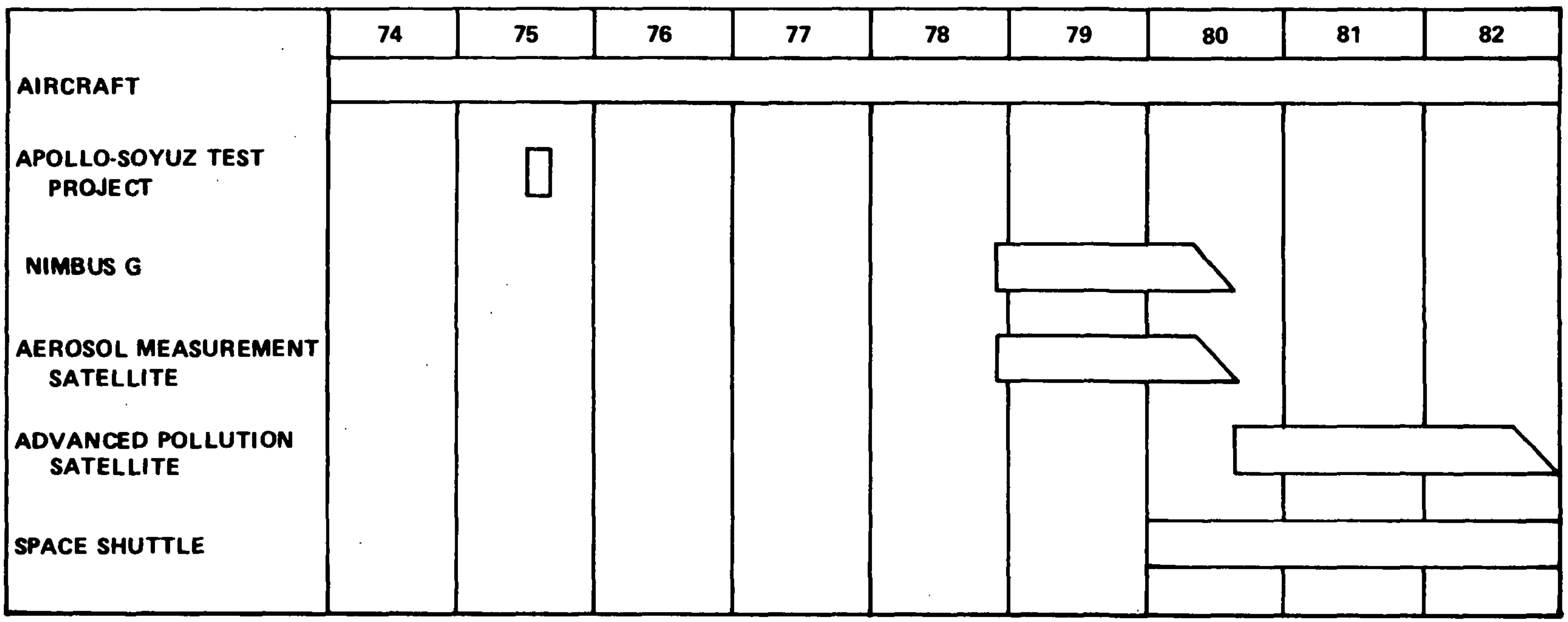

Figure III-22. Environmental quality monitoring missions.

4. PROGRAM FUNDING

The Environmental Quality Program Funding is shown in Figure III-23 and Table III-9. Four key program elements are depicted. These are:

1. Research — This effort is planned to be maintained at $2.8 million per year through FY-1980.

2. The new research initiatives proposed for FY-1976 are related to regional and stratospheric pollution monitoring efforts.

3. The Nimbus-G buildup and runout is the major portion of the total funding in FY-1975 and FY-1976, where it builds to approximately $25 million per year.

4. The new flight programs consist of the Stratospheric Aerosol and Gas Experiments (SAGE) and the second-generation Pollution Monitoring Mission (EOS-B) to follow Nimbus-G. This funding compensates for the diminishing Nimbus-G effort and levels off the total Environmental Quality Program at about the $30 million per year level.

TABLE III-9. ENVIRONMENTAL QUALITY PROGRAM FUNDING HISTORY (MILLIONS OF DOLLARS)

	73	74	75	76	77	78	79	80
Research	2.3	2.8	2.8	2.8	2.8	2.8	2.8	2.8
New Research Initiatives				7.0	7.5	7.0	7.0	7.0
Nimbus-G		9.0	25.0	23.0	10.4	6.8	3.3	
New Flight Programs (for Planning Purposes)				2.0	9.6	12.4	19.0	16.0
Totals	2.3	11.8	27.8	34.8	30.3	29.0	32.1	25.8

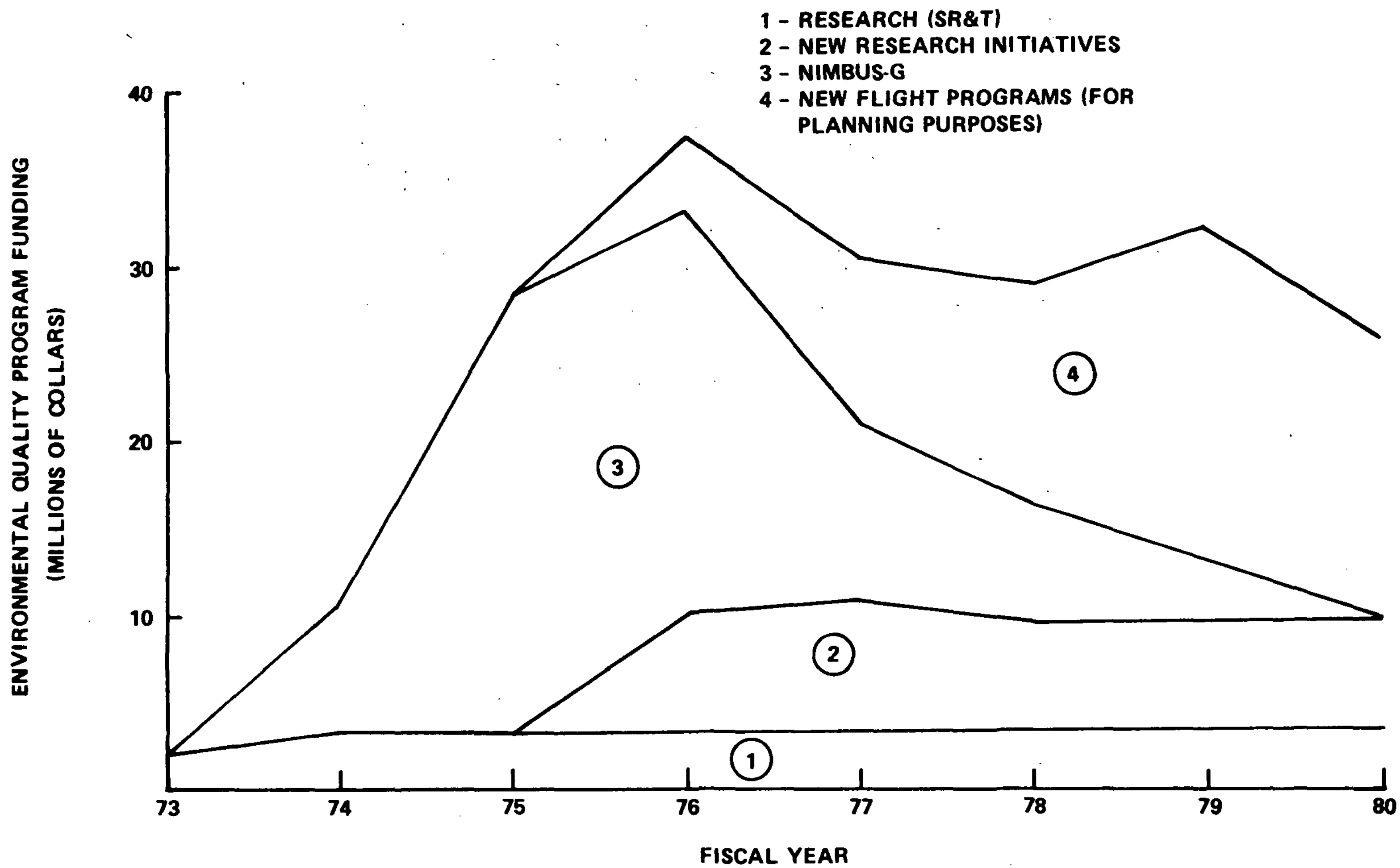

Figure III-23. Environmental Quality Program funding (millions of dollars versus fiscal year).

5. REFERENCES

1. Useful Applications of Earth-Oriented Satellites — Meteorology. National Academy of Sciences, Washington, D.C., 1969.

2. Man's Impact on the Global Environment — Report of the Study of Critical Environmental Problems (SECP). MIT Press, 1970.

3. Remote Measurement of Pollution. NASA SP-285, 1971.

D. Flight Mission Summary

Table III-10 presents the FY-75 flight mission summary for earth observations. Each of the projects is briefly discussed in the following paragraphs.

1. NIMBUS

The Nimbus program has served as the primary space research and development tool of the Weather and Climate discipline for NASA. Five successful missions have been accomplished since 1964, and another (Nimbus-F) is scheduled for launch in 1974. The sensors developed in this program provided the innovation and space testing prerequisite to operational implementation. The latest of the series, Nimbus-G, which is scheduled for launch in 1978, will concentrate on the observation of atmospheric pollutants and oceanographic parameters from spaceborne sensors.

2. SYNCHRONOUS METEOROLOGICAL SATELLITE

The SMS will provide continuous day and night imaging of clouds and the earth from a geosynchronous platform. The continuous frequency of coverage provided by this imaging will enhance our knowledge about storms and other short-lived weather and climate phenomena. These satellites will serve as the prototypes for the Geostationary Operational Environmental Satellite Program of NOAA.

3. SEVERE STORM OBSERVING SATELLITE

This mission is an advanced version of SMS and will provide continuous sounding of the atmosphere in addition to day and night imaging from a geosynchronous orbit. In addition, a significant increase in sensor dwell time will be provided by the incorporation of a three-axis stabilized attitude control system aboard the spacecraft.

4. TIROS

The Tiros R&D program has periodically provided operational prototype spacecraft to initiate a new series of NOAA operational satellites. The

TABLE III-10 EARTH OBSERVATIONS: FY-75 FLIGHT MISSION SUMMARY

CY / Project	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82
Nimbus		III	IV		V		F				G				
SMS							A B								
Severe Storm Observing Satellite												A			
TIROS			M							N					O
Radiation Budget Satellite													A		
EOS												A		B	
SEOS														A	
ERTS					A			B			C				
Heat Capacity Mapping Mission										A					
Applications Explorer											B	C	D	E	F
Sortie													2	2	2
EREP							SL 2, 3, 4								

Approved and Ongoing.

latest of these, TIROS-N, will be launched in 1977, and will carry both day and night imaging capability via the Advanced Very High Resolution Radiometer (AVHRR) and sounding capability via the TIROS Operational Vertical Sounder (TOVS).

5. RADIATION BUDGET SATELLITE

Global monitoring of the earth's radiation budget is fundamental to the problem of long range climatic forecasts. The earth orbiting satellite provides an ideal platform for maintaining close monitoring of this balance. A prototype R&D system to monitor the earth's radiation budget is planned for implementation in 1979.

6. EARTH OBSERVATORY SATELLITE

The EOS will be the second generation R&D spacecraft of the 1980's, replacing Nimbus and serving all disciplines in earth observations. It will be modular designed, Shuttle compatible, and capable of accommodating the larger instruments proposed for implementation in the 1980's. The first mission, planned for 1979, is a water and land use mission and will utilize a thematic mapper and a high resolution pointable imager to obtain high resolution imagery for earth resources survey. The second planned mission in 1981 will be a pollution and oceanographic mission that will build upon and extend the capabilities initiated by Nimbus-G.

7. SYNCHRONOUS EARTH OBSERVATORY SATELLITE

The SEOS, planned for launch in 1981, will perform earth observations via a telescope from synchronous orbit to provide continuous high resolution imagery that will serve applications in the areas of mesoscale weather phenomena and earth resources. The prime payload planned to perform these measurements will be the Large Earth Survey Telescope (LEST).

8. EARTH RESOURCES TECHNOLOGY SATELLITE

The ERTS mission has provided a large volume of visible and infrared earth surface imagery over a period of several seasons via a four-band multispectral scanner (MSS) and Return Beam Vidicon (RBV). The ERTS-B

flight will carry instrumentation identical to ERTS-A. ERTS-C is planned to provide a sensor innovation by adding a fifth channel (thermal) to the MSS.

9. HEAT CAPACITY MAPPING MISSION

The HCMM will obtain thermal data at the extremes of the diurnal cycle (approximately 2 a.m. and 2 p.m.) in order to generate thermal maps. The thermal inertia measurements derived from these maps will allow rock types to be distinguished which can lead to the location of mineral resources, gas, and oil, etc.

10. APPLICATIONS EXPLORER

The Applications Explorer Program is designed to accommodate dedicated earth observations missions having unique orbital requirements. The spacecraft is configured to be a low cost, quick reaction, Scout-launched spacecraft. One mission is planned per year to support these requirements.

11. SHUTTLE SORTIE MISSIONS

The Shuttle Spacelab, which is initially planned for 7-day flights, will be utilized by earth observations disciplines to perform sensor development, to conduct experiments which utilize the zero gravity environment, and to perform certain specialized missions such as obtaining imagery from targets of opportunity. The presence of man coupled with the high weight, volume, and power capabilities that are available on the Shuttle allow the accommodation of large sensors (particularly microwave) which have previously been precluded.

12. EARTH RESOURCES EXPERIMENT PACKAGE

Man-controlled sensors were utilized in the Skylab EREP on missions SL-2, -3, -4 which ended in early 1974. A significant amount of earth resources data was obtained and is presently being analyzed by the EREP investigators. The use of man in remote sensing systems was demonstrated and serves as an example of Shuttle-era space remote sensing systems.

CHAPTER IV. THE EARTH AND OCEAN PHYSICS APPLICATIONS PROGRAM

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

CHAPTER IV. THE EARTH AND OCEAN PHYSICS APPLICATIONS PROGRAM

1. HISTORY

The NASA Earth and Ocean Physics Applications Program (EOPAP) had its origins in the National Geodetic Satellite Program (NGSP) which is now being completed after a decade of fruitful activity. The goals of NGSP included the determination of the location of reference system associated with the earth's center of mass and the determination of the gravitational field coefficients with corresponding accuracy, i.e., to five parts in 10^8. These goals have been met through analyses based on satellite tracking data obtained by means of Baker-Nunn cameras and radio tracking systems whose capabilities corresponded to accuracies of the order of 10 meters in satellite position.

Advances in the development of lasers in the latter part of the last decade hold the promise of having greatly improved tracking systems with accuracies in the 1 to 0.1 meter range during the 1970's. This prospect had begun to stimulate thinking about ways to use such capabilities to attack new kinds of geophysical problems at the time of the last Applications Summer Study, in 1968 [1]. The 1968 Summer Study on Space Applications did, in fact, provide a strong impetus which was a key factor in the sequence of events leading to the establishment of the NASA EOPAP. It pointed the way directly by calling for laser tracking, a satellite altimeter, a zero-drag system, and studies of a system for sensing the gravity field.

The following year a conference sponsored by NASA was held at Williamstown, Massachusetts. Scientists representing a number of solid-earth and ocean physics disciplines gathered to consider the several types of geophysical research which could be conducted using the emerging space techniques and which could reasonably be expected to lead toward practical applications at some time in the future. The report of the proceedings of this Conference contained much valuable material which, to a considerable extent, served to define the scientific and applications bases for new departures in the field of geodesy [2].

The specific recommendations of that landmark study were stated in the following terms:

The Williamstown Conference Group recommended that NASA undertake an integrated solid-earth and ocean physics program with several goals. These included the long range objectives of developing drag-free and altimeter

satellites which would be tracked from distant satellites to measure the geopotential and mean sea level accurately enough to determine the general circulation of the oceans and to set firm bounds on the long-term mechanics of the earth's interior. Gravity field spatial resolution of 100 km half-wavelength was established as the long-range goal and it was indicated that 250 km spatial resolution would be of genuine value, greatly enhancing oceanographic and geotectonic analyses. Further, it was recommended that laser ranging and very long baseline interferometry (VLBI) systems be developed to obtain relative positions of points on the earth's crust to 2 cm accuracy in order to monitor relative rates of motion of different points on the earth's crust well enough to infer irregularities in tectonic plate motions. Also, this accuracy could be used to monitor polar motions and earth rotation variations to infer their excitations and dampings and to determine the orbits of the distant satellites specified above for tracking the drag-free and altimeter satellites. It was also recommended that improved systems be developed to determine ship and buoy positions and motions, and for transmitting data from remote platforms via satellite. Finally, it was recommended that companion fundamental research programs with large-scale computer use by supported at a commensurate level.

The next several years were devoted to formulating a comprehensive plan for actually achieving the goals set forth in the Williamstown Conference Report. This plan was issued in 1972 as the NASA EOPAP [3]; it charted activities for a decade into the future.

The initial steps contemplated have already been taken, and the EOPAP endeavor is, in fact, proceeding according to the plan.

The satellites launched during the NGSP are indicated in the schedule seen in Figure IV-1.

2. GOALS AND OBJECTIVES

EOPAP is based on the discipline of earth dynamics. Its primary goals are to identify, develop, demonstrate, and utilize relevant space measurement techniques that will provide data for the development and validation of predictive models for earthquake-hazard alleviation, ocean-surface conditions, and ocean circulation.

Earth dynamics includes solid-earth and ocean dynamics, disciplines of great practical importance. Solid-earth dynamics is concerned with the physical motions and distortions of the solid earth that are responsible for earthquakes, tidal waves, volcanic eruptions, mineral differentiation, and

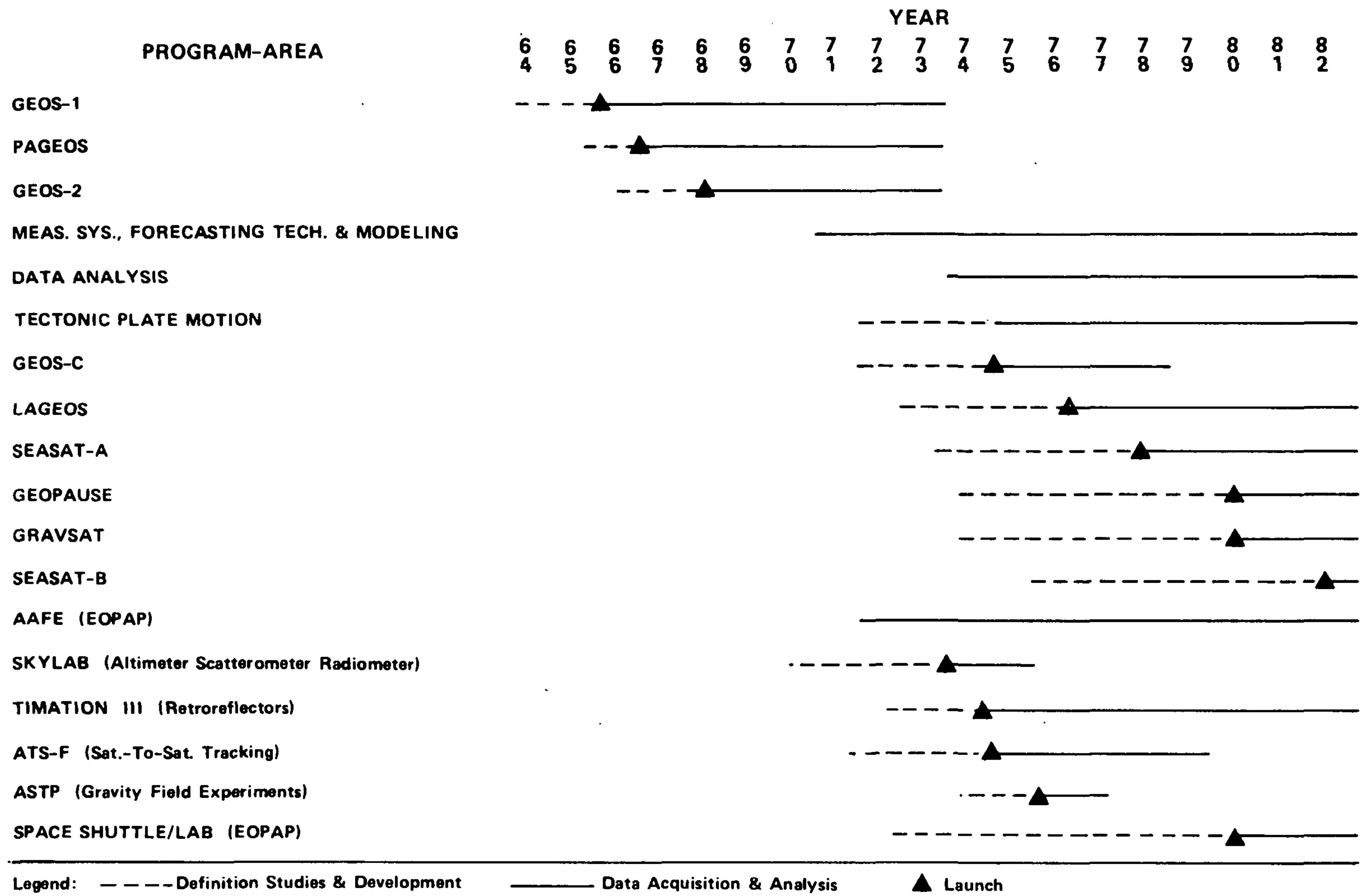

Figure IV-1. The National Geodetic Satellite Program (NGSP).

mountain building. Ocean dynamics embraces ocean circulation and the physical state of the ocean surface, both of which are clearly of direct concern to ships at sea and to population centers bordering the oceans. Further, ocean dynamics is intimately related to climate and weather in all parts of the world. A thorough understanding of earth dynamics is fundamental to intelligent management of the earth, and the average American will readily recognize the needs and benefits of increasing our scientific knowledge and capabilities in this area.

The importance of earth dynamics is reflected in the efforts of a large number of agencies both in this country and abroad, and in the organization of large-scale cooperative programs such as the International Decade of Ocean Exploration (IDOE) and the Geodynamics Project.

A central theme of EOPAP is to provide a forum for a broad cooperative effort for the development of practical tools — predictive models and observational systems — whose outputs can ultimately be used by operating agencies, such as the National Oceanic and Atmospheric Administration (NOAA) and the U.S. Geological Survey (USGS), to the social benefit of this nation and, indeed, of the whole world.

The objectives of the Earth and Ocean Physics Applications Program fall naturally into two major categories — (Solid) Earth-Dynamics Applications and Ocean-Dynamics Applications — and the program has been similarly divided. However, since the geophysics and the space measurement techniques are largely the same, an implementation plan that encompases both areas has been developed.

The EOPAP is directed toward development and validation of the following major applications objectives:

- Methods leading to earthquake-hazard assessment and alleviation models to predict probable time, location, and intensity of earthquakes.

- Means for predicting the general ocean circulation, and surface currents and their transportation of mass, heat, and nutrients.

- Methods for synoptic monitoring and predicting of transient surface phenomena, including the magnitudes and geographical distributions of sea state, storm surges, swell, surface winds, etc., with emphasis on identifying existing and potential hazards.

• Refinement of the global geoid; extension of geodetic control to inaccessible areas, including the ocean floors; and expansion of knowledge of the geomagentic field for mapping and geophysical applications to satisfy stated user requirements.

Major areas of interest are as follows:

SOLID-EARTH DYNAMICS	OCEAN DYNAMICS
<u>Earthquake-Hazard Assessment</u>	
Tectonic Plate Structure and Motion	Currents
Fault Motions	Circulation
Sea-Floor Spreading	Tides
Polar-Motion Variations	Sea State
Earth-Rotation Variations	Pile-Up
Solid-Earth Tides	Storm Surges
Gravity Field	Tsunamis
Magnetic Field	Air/Sea Interaction
	Surface Winds
<u>Global Surveying and Mapping</u>	
Gravity Field (including the oceanic geoid)	
Magnetic Field	
Station Locations	
Mineral and Oil Resources	

The overall program logic used for EOPAP can be seen in Figures IV-2 and IV-3. Progress in solving the problems of environmental management and the alleviation of natural disasters will be quite limited until there is a better understanding of the physical forces at work and the physical mechanisms that respond to these forces. That will not come easily if studies are limited to geographic areas or to isolated phenomena. Earth dynamics is very complex, involving strong interactions among events in different parts of the globe and in the atmosphere, oceans, and solid earth. This precludes any possibility of finding solutions in terms of simple theoretical descriptions. Predictions of earthquakes, storm surges, and other catastrophic natural events will almost certainly have to be based on strongly empirical numerical computer models that require, as operational inputs, very large numbers of very recent synoptic data from large geographic areas. Further, extraordinary measuring accuracies will be needed to detect such things as motions of the crust in fault zones, which are a few centimeters per year at most. These accuracies must be attained not just as a one-time laboratory effort but routinely in remote and sometimes inhospitable regions of the world.

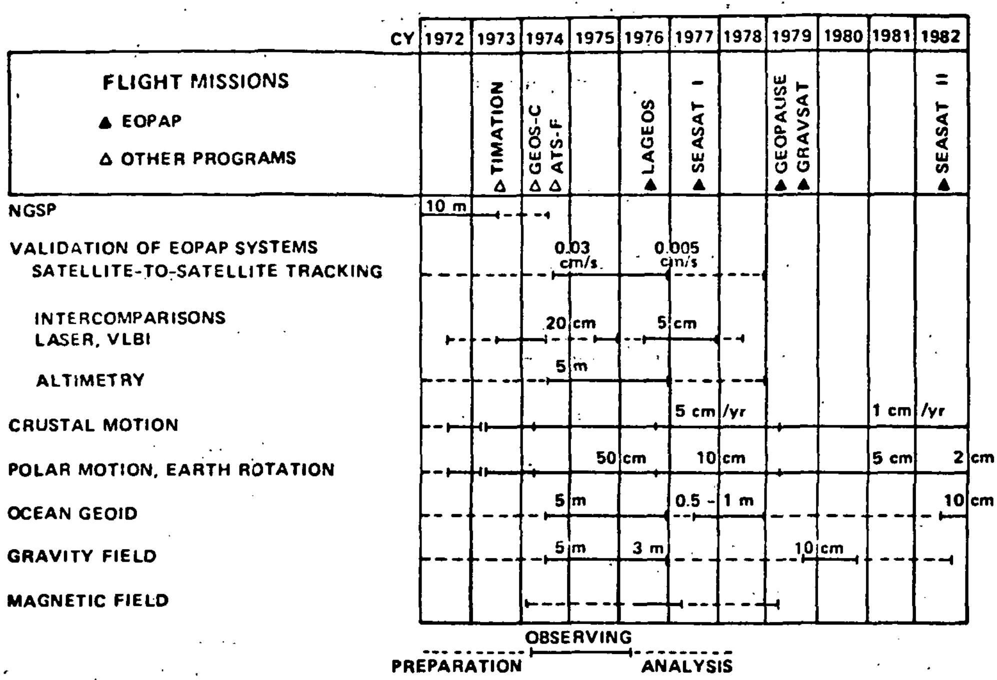

Figure IV-2. Earth Dynamics Experiments.

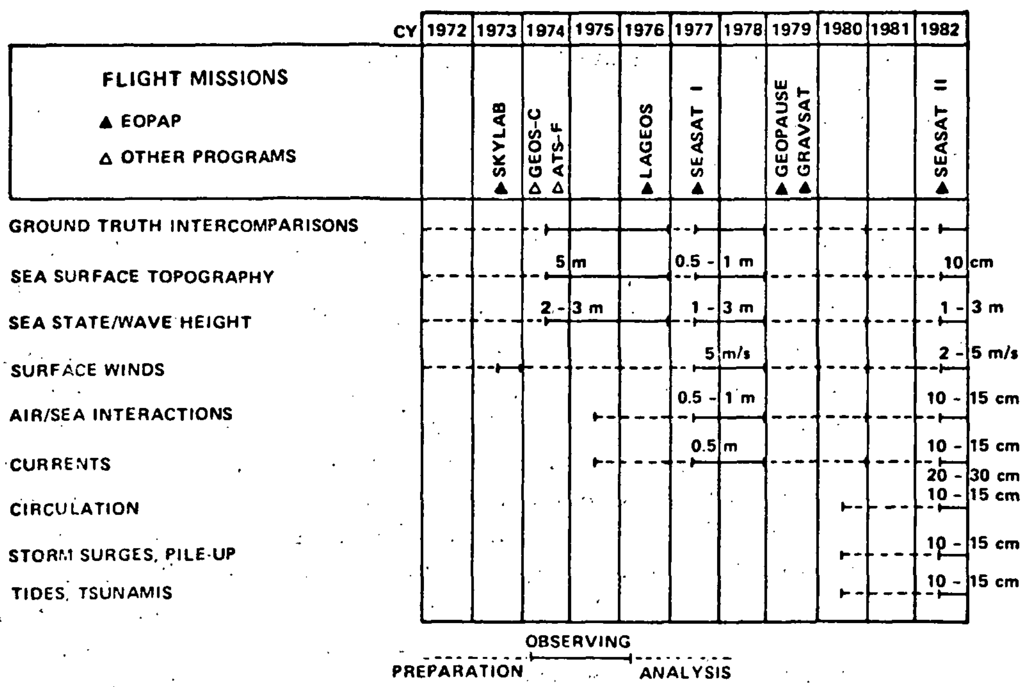

Figure IV-3. Ocean Dynamics Experiments.

Surface-based measurements are absolutely necessary in earth-dynamics program, and substantial progress has already been achieved within existing programs in many sectors of earth dynamics. On the other hand, it is difficult to conceive of an effective operational system for reporting sea state, as an example, that does not require frequent and prompt reporting of sea-state observations from all parts of the world ocean. This is feasible only by means of satellites — both for making remote observations and for collecting data from in situ sensors.

EOPAP is based on the fact that the use of satellites and space techniques is the only way to provide the large body of new data required for the solutions of significant problems in earth and ocean dynamics. Some particular characteristics of space techniques that establish this unique role follow:

a. Space techniques provide access to a stable inertial reference (the star background) or to quasi-inertial references (the moon and artificial satellites), which is essential for determining the earth's rotation and polar motion and is of great importance in sorting out the complex motions of points on the earth relative to one another.

b. Artificial satellites, the moon, and the stars can serve as geometric references, visible simultaneously from widely separated points.

c. Satellites provide rapid and repeated global coverage.

d. Satellites are the most stable and most accurately positioned mobile platforms available for observations over large geographic areas.

e. Space observations have minimum path length in the atmosphere, thereby minimizing atmospheric-propagation errors, the basic limitation to all high-precision distance and angle measurements.

The development of many of the basic techniques to be used in this program was initiated under the National Geodetic Satellite Program, a major interagency program in geodesy, and under other NASA programs. It was recognized quite early that techniques such as laser ranging systems, VLBI, radar altimeters, and satellite-to-satellite tracking could achieve precisions necessary for probing the dynamic processes of the earth.

The fundamental tools to be used in the EOPAP will be laser ranging to satellites and the moon, VLBI, satellite altimetry, scatterometry and radiometry, and satellite-to-satellite tracking (SST). For earthquake-hazard assessment and alleviation, laser ranging and VLBI will be used to measure tectonic plate motion, regional strain buildup, polar motion, and universal time (UT-1). The refined geoid will be developed with the assistance of satellite-to-satellite

tracking and satellite altimetry, and the magnetic field will be mapped in detail with satellite-borne vector magnetometers.

All the required space techniques have been implemented with the exceptions of satellite-borne gravity gradiometry. Large quantities of experimental data have been analyzed and the significant error sources have been identified. Moreover, many corrective measures have already been demonstrated experimentally, such as two-wavelength optical correction for tropospheric propagation and two-frequency RF correction for ionospheric effects. There are, of course, many developmental tasks in the area of technology and increased measurement accuracy, but these are largely concerned with more precise experimental determination of various error sources, with experimental evaluation of corrective methods, and with the design of efficient operational systems.

The program will rely heavily on the seven retroreflector satellites now in orbit, on Skylab, on the Earth Resources Technology Satellite (ERTS), and on other missions that are already approved. In addition, EOPAP will require several dedicated spacecraft to support the required measurements. The Navy's TIMATION III, a high-orbiting, retroreflector-equipped satellite, will be used for measurements of solid-earth dynamics. At the 20- to 30-cm accuracy level, Geodynamic Experimental Ocean Satellite C (GEOS-C), which is being launched under the NGSP, will provide the first testbed for the radar-altimeter and the satellite-to-satellite tracking systems, the fundamental tools with which EOPAP is being built. The Laser Geodynamic Satellite (LAGEOS) will provide a stable reference platform for long-term measurements of the earth's dynamic properties; this is a passive, high-orbiting, high-density spacecraft.

Two oceanographic satellites, Sea-State Satellites (SEASAT) 1 and 2, will provide the first test of integrated oceanographic systems for synoptic monitoring of ocean-surface properties. These missions will be built from the experience gained from GEOS-C, Skylab, ERTS, and GRAVSAT, which will use the satellite-to-satellite tracking system to map the trails of a refined geoid for the Ocean Dynamics and the Earth Dynamics Applications. A platform from which the satellite-to-satellite tracking will be carried out will be a high-orbiting satellite GEOPAUSE, whose primary function is to provide a general frame of reference for the EOPAP measurements.

EOPAP will augment activities now under way in other agencies. It has been developed in consultation with these agencies and is structured to provide critical information that can be supplied uniquely by space techniques. In carrying out this program, much interagency coordination and many cooperative efforts are contemplated. In earthquake research, NOAA and USGS are engaged in local ground-based surveying and seismic monitoring programs to measure localized crustal motions and strain buildup over small regional areas.

Under EOPAP, measurements of stations several hundred or even thousands of kilometers apart will yield data about tectonic plate motions and regional strain fields that give rise to earthquakes. An experiment using NASA satellite-tracking lasers in cooperation with NOAA, USGS, and the Lamont-Doherty Geological Observatory is being undertaken in the San Andreas region of California to help determine the stored energy of the fault. In the field of ocean dynamics, both NOAA and the Naval Research Laboratory (NRL) have been working closely with NASA; both were consulted in many aspects of the planning for EOPAP. Representatives from NOAA participated in the writing of the Ocean-Dynamics Applications portion of the program.

In 1969, NASA sponsored the Williamstown Conference on Terrestrial Environment: Solid-Earth and Ocean Physics for guidance on how to apply available capabilities to meaningful objectives in the geophysical sciences. Although the attendees were primarily from the scientific community, they formed many of their recommendations around potential results of practical benefit, such as better understanding of those mechanisms involved in earthquakes and ocean dynamics. This program incorporates many of the recommendations from that Conference.

EOPAP offers an excellent opportunity for international cooperation. In fact, if the program is to be meaningful, there must be cooperation between the U.S. and other countries, in at least tracking support or tracking-site locations. Past experience shows that other countries are eager to participate actively in cooperative programs in geophysics. Two pertinent examples of this are the cooperation in satellite geodesy [International Satellite Geodesy Experiment (ISAGEX)] and the U.S./USSR bilateral exchange of data during the earth's magnetic-field survey. There is every indication that this cooperation will not only continue but increase in scope as the program gets under way.

3. IMPLEMENTATION

a. Summary. The broad outlines of the overall EOPAP plan are briefly stated in the following paragraphs.

The EOPAP plan has been designed specifically to develop and demonstrate space-derived techniques for observing the earth's dynamic motions to make unique contributions to the knowledge of earthquake mechanisms and the development of earthquake prediction approaches, and for monitoring and forecasting ocean surface conditions on a global, near-real-time basis.

The Earth Dynamics portion of the program is aimed at the measurement of crustal motions near earthquake fault zones and detection of polar motion anomalies which are thought to precede earthquakes.

The Ocean Dynamics portion of the program is directed toward the measurement and prediction of ocean surface conditions including wave heights and directional spectra, surface winds, and ocean temperatures, as well as the mapping of ocean currents and circulations.

The program has several major elements designed to achieve these objectives. They are:

(1) Determination of crustal motions both within and among the tectonic plate, including regional strain field mapping and dilatancy monitoring at earthquake fault zones.

(2) Determination of gravity field and geoid with accuracies of 10 cm and space resolutions of about a degree needed to meet the Earth Dynamics objectives by providing information about tectonic plate structure and plate motion driving mechanisms, and to meet the Ocean Dynamics objectives by providing the geoid needed as a reference for the proper interpretation of sea surface topography measures.

(3) Determination of sea surface topography relative to this reference goeid with 10 to 15 cm accuracy to provide information about currents, including meanders; ocean circulations; and eddies.

(4) Monitoring and prediction on a near-real-time basis of ocean surface conditions, including wave directional spectra, surface winds, and ocean surface temperatures.

Two techniques offer the promise of achieving the extreme accuracies required for measuring crustal motions; they are laser tracking of satellites, and VLBI. Both are being developed to determine which is most effective and, also, to provide the independent checks of each other's results, which will help to develop the assurance in the accuracy of the results.

The 5,900 km altitude will effectively decrease gravity perturbation uncertainties, yet will permit tracking by a relatively large number of lasers which can view the satellite in its 110 degree inclination, which will give good tracking geometry from all of the sites of interest over the globe. The high

areal density will greatly decrease the errors due to radiation pressure. The spherical shape of the surface-mounted retroreflector array will render negligible the errors associated with the retroreflection.

The actual mapping of the fault motions in sufficient detail to detect and monitor dilatancy will be accomplished by GEOPAUSE, a spacecraft now being developed, with a 1980 launch anticipated [4, 5]. This second generation spacecraft capability will permit, for the first time, determination of the reliability of using dilatancy monitoring as an earthquake prediction indicator. It is anticipated that advanced spaceborne laser systems for GEOPAUSE will be validated in an Applications Spacelab Mission [6, 7].

The determination of the gravity field is being approached by studying three alternative methods, namely,

(1) Satellite-to-satellite tracking between a high satellite and a low satellite, so-called "high-low" approach.

(2) Satellite-to-satellite tracking between a pair of low altitude satellites in the same orbit, the so-called "low-low" approach.

(3) The gravity gradiometer approach.

GRAVSAT mission studies now under way are aimed at selecting the most effective approach to meeting this objective in the context of the overall EOPAP program [8, 9].

The high-low approach will actually be tested in space in three experiments:

(1) The extensive GEOS-C/Applications Technology Satellite F (ATS-F) and Nimbus-F/ATS-F satellite-to-satellite tracking experiments scheduled to begin later this year at altitudes of 1100 and 800 km, respectively.

(2) The Apollo-Soyuz Test Project (ASTP)/ATS-F proof test satellite-to-satellite tracking experiment to be conducted at 250 km altitude in 1975.

(3) A companion low-low approach proof test will also be conducted during the ASTP mission [10, 11].

Monitoring and prediction of the ocean surface conditions, namely, waves, winds and temperatures, will be demonstrated by SEASAT-A in 1978.

This spacecraft will also carry a 10-cm altimeter system, which will permit tests of the ability to accurately determine sea surface topography in local regions where 5-cm laser tracking is available [12-14]. It is anticipated that the sea surface topography is to be determined to 10-cm accuracy on a global basis by SEASAT-B, which will carry a 10-cm altimeter and will be tracked by the GEOPAUSE spacecraft and lasers.

An important step toward these missions will be taken later this year with the launching of GEOS-C which will include a 1-meter altimeter for global surveys of sea surface topography and wave heights. In-orbit proof-of-concept tests of the altimeter, radiometer, and scatterometer have already been conducted in the Skylab mission. Additional instruments and systems for SEASAT-B and GEOPAUSE-B will be validated in Spacelab flights at the beginning of the 1980's.

The relationships of the planned experiment programs to the flight missions are indicated in Figures IV-2 and IV-3; the progress looked for in quantitative terms is indicated there.

The approach being taken to achieve these many objectives involves three kinds of activities, (1) the fundamental research and development, (2) the EOPAP flight missions, and (3) related flight missions which incorporate EOPAP experiments.

b. Research and Development. The EOPAP research and development (R&D) activity is carried on under a pair of program elements, one concerned with measurement systems and forecasting techniques, the other with data analysis [15].

Experiment Data Analysis provides for analysis of data obtained in the Earth and Ocean Physics Applications program, including data obtained from earth-based satellite experiments. The analysis of such problems as monitoring sea state, mapping ocean currents and global circulation patterns, monitoring a wide range of dynamic disturbances of the oceans, interaction between ocean and atmosphere, and a variety of earth motion factors relating to earthquakes, such as polar motion, earth rotation veriations and crustal motion using data gathered by applying space techniques, is provided for in this activity.

Measurement Systems and Forecasting Techniques activities involve the establishment of a base of analytical and experimental techniques and feasibility demonstrations which are required for the orderly development and implementation of the Earth and Ocean Physics Applications program. Through this activity

it is possible to demonstrate the applicability and merits of using space technology and associated metric measurement techniques to investigate the dynamics of the solid earth and oceans and also to establish a stable and integrated base of science and technology, analytical and experimental techniques, system studies, and feasibility demonstrations, which are required for the orderly development and implementation of the EOPAP. The resources to improve models and measurement systems as technical objectives warrant improvement is also provided here. These activities in turn are designed to contribute to a better understanding of ocean dynamic processes and earthquake mechanisms, their impact on man and his environment, and means for applying the benefits of this knowledge through the development of forecasting techniques.

The specific topics addressed in each of these two major R&D activities are grouped under several major headings, namely, planning, solid-earth dynamics and earthquake prediction, ocean dynamics monitoring, geodesy and global surveying and mapping, surface measurement techniques, and flight systems.

The research and development program proceeds not only under EOPAP program elements, per se, but also under the Advanced Applications Flight Experiments (AAFE) Program and the Aircraft Program of the Office of Applications [16]. The development of advanced versions of instruments such as the altimeter and the coherent imaging radar is, for example, presently being conducted under these programs.

c. Complementary Flight Programs and Demonstrations. The EOPAP flight programs, per se, are complemented by a major ground-based EOPAP program element, the Tectonic Plate Motion Program, and by key EOPAP experiments involving flight missions conducted by other NASA program offices and by the Department of Defense (DOD). Skylab has already furnished the basic in-orbit proof-of-concept tests of the altimeter, the scatterometer, and the microwave radiometer. Satellite-to-satellite tracking experiments are to be conducted in connection with three missions pairs: GEOS-C/ATS-F, Nimbus-F/ATS-F, and Apollo/ATS-F, the latter being carried out as part of the ASTP activity.

TIMATION III, a DOD spacecraft, is being fitted with an array of laser retroreflectors which will permit it to be tracked by accurate lasers now being developed. In a 14,000 km orbit, it will be useful in conducting polar motion experiments, paving the way for LAGEOS pole motion monitoring investigations. The Tectonic Plate Motion Program is discussed in the following paragraphs. The satellite-to-satellite tracking experiments and the Skylab tests are discussed here and in the next section.

(1) The Tectonic Plate Motion Program. The Earth Dynamics portion of the EOPAP is aimed at making key measurements which are expected to contribute significantly to the development of an earthquake prediction capability. These include the measurement of the earth's crustal motion near the earthquake fault zones and the behavior of the earth as a whole as it rotates about its polar axis.

The earth is covered by approximately six large tectonic plates of continental proportions, as well as a number of smaller ones. These plates, some 100 km thick, are slowly moving relative to each other. At the San Andreas Fault, for example, the plate which cradles most of the Pacific Ocean is sliding northward relative to the plate on which North America rides, as Figure IV-4 indicates. The scraping of one plate by another is not a completely smooth motion, and, in fact, generates a number of earthquakes, some as large as the 1906 San Francisco and 1971 San Fernando earthquakes which wrought great havoc.

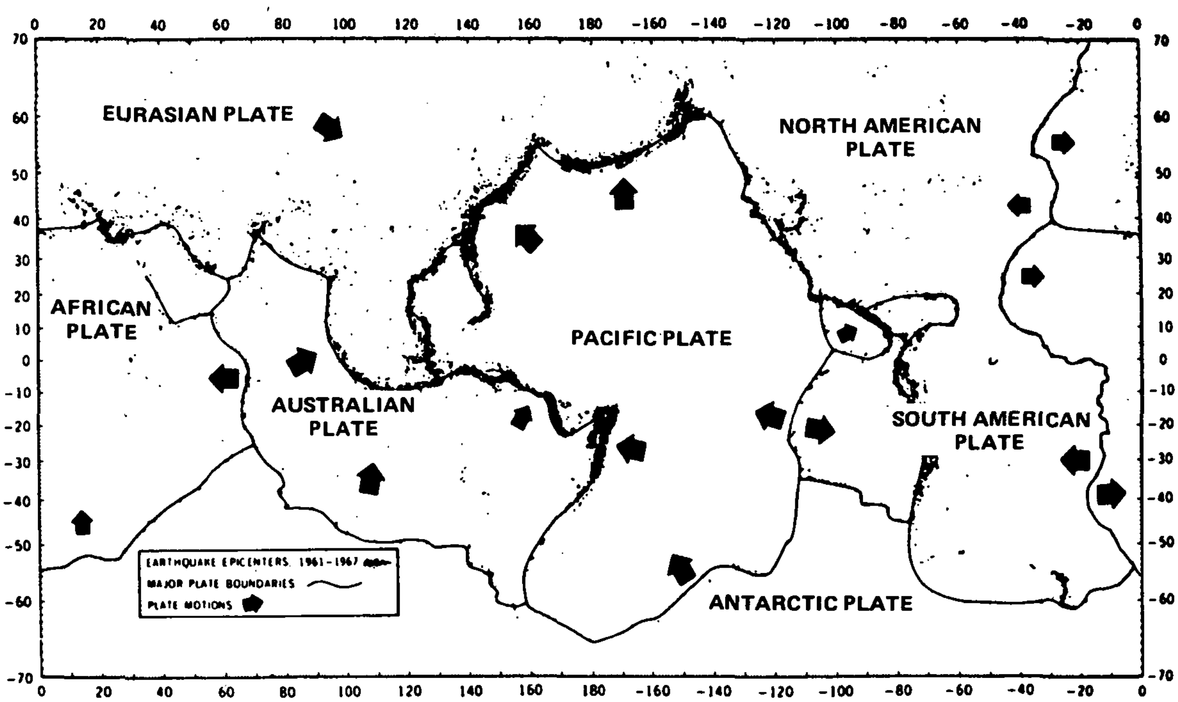

Figure IV-4. Major tectonic plates.

An experiment is being conducted to measure displacement along the San Andreas Fault in California between points widely spaced along and far away from the fault. This San Andreas Fault Experiment (SAFE) activity (Fig. IV-5) is being conducted in collaboration with USGS and the Lamont-Doherty Geophysical Observatory of Columbia University. The experiment will employ

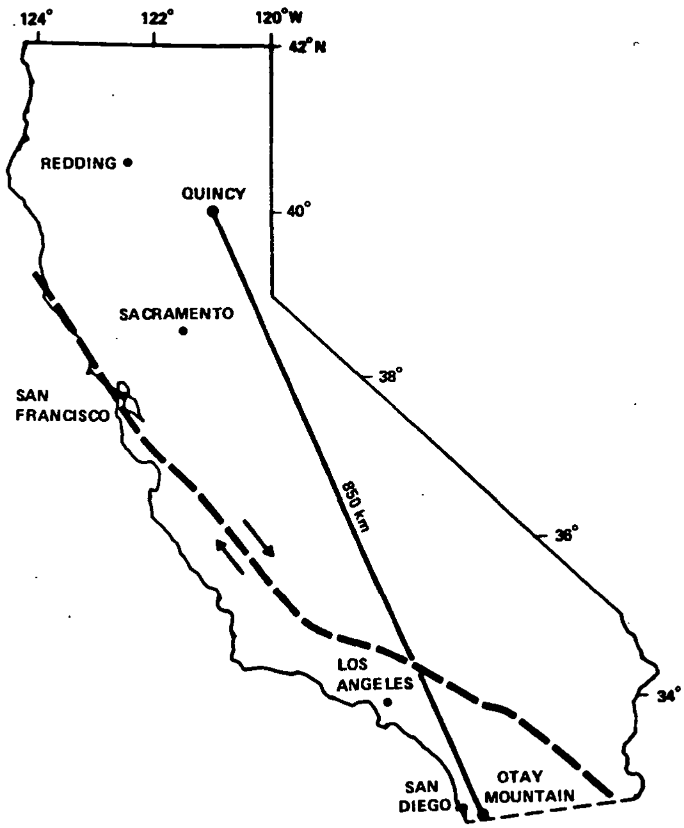

Figure IV-5. San Andreas Fault Experiment.

laser ranging to satellites to measure precisely the distance of earthquakes in the Western United States. In 1972, two initial sites were selected for this experiment — Quincy, in the Plumas National Forest in northerm California, and San Diego. Laser tracking systems were established at each of the sites temporarily last year to obtain preliminary measurements and to check out the data analysis computers and software. Activity in this element of the Tectonic Plate Motion Program is expected to start this year.

The other two elements of this program exploit the VLBI technique which relies on the tracking of radio stars to obtain the necessary accuracy in determining positions and motions of the earth's crust. One of these, the Astronomical Radio Interferometric Earth Surveying (ARIES) Experiment (Fig. IV-6), will demonstrate the capability of this powerful technique in the California area. As shown in Figure IV-7, the other Pacific Plate Motion Experiment (PPME) will extend this approach to Alaska and to Hawaii on the Pacific Plate. The aim of this coordinated set of experiments is to get a

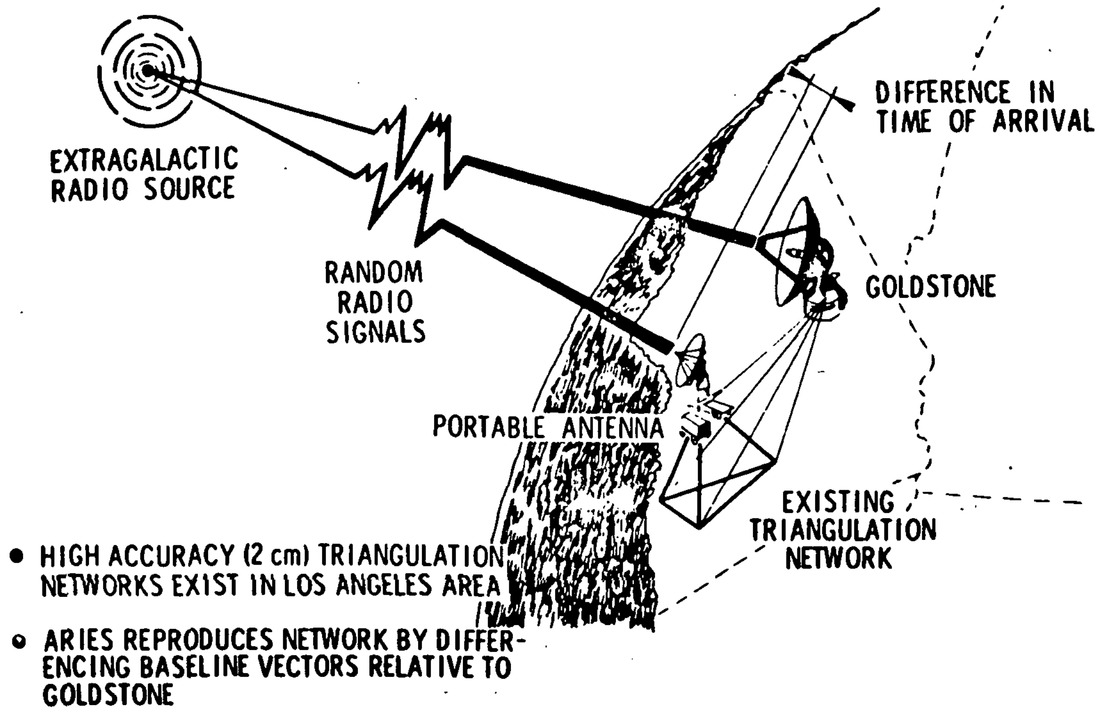

Figure IV-6. Astronomical-Radio Interferometric Earth Surveying Experiment (ARIES).

consistent picture of the motion both in the plate boundary region extending from Southern California to Alaska and over the plate as a whole, where stations at more distant points such as Hawaii, North Carolina, and Massachusetts can tell us about the main motion of the plates and also can serve as reference points for sorting out the complex activity in heavily faulted regions such as the California-Nevada area. These phenomena are, in fact, part of a world-wide pattern of activity as Figure IV-4 indicates.

(2) Skylab Experiments. The EOPAP Ocean Dynamics Program moved from the preparatory and flight test stage to an orbital phase with the launching of the Skylab Workshop and Command Module. This orbiting facility was outfitted with an Earth Resources Experiment Package (EREP) which included a radar altimeter, a radiometer, and a scatterometer, three key instruments which are basic tools of the EOPAP Ocean Dynamics Program [17]. The concepts on which these three new pieces of equipment were based were actually proven in orbit during the Skylab Mission. The pulse altimeter, for example, verified for the first time by means of direct orbital measurements that the sea surface does indeed dip by some 15 meters near the Puerto Rican trench

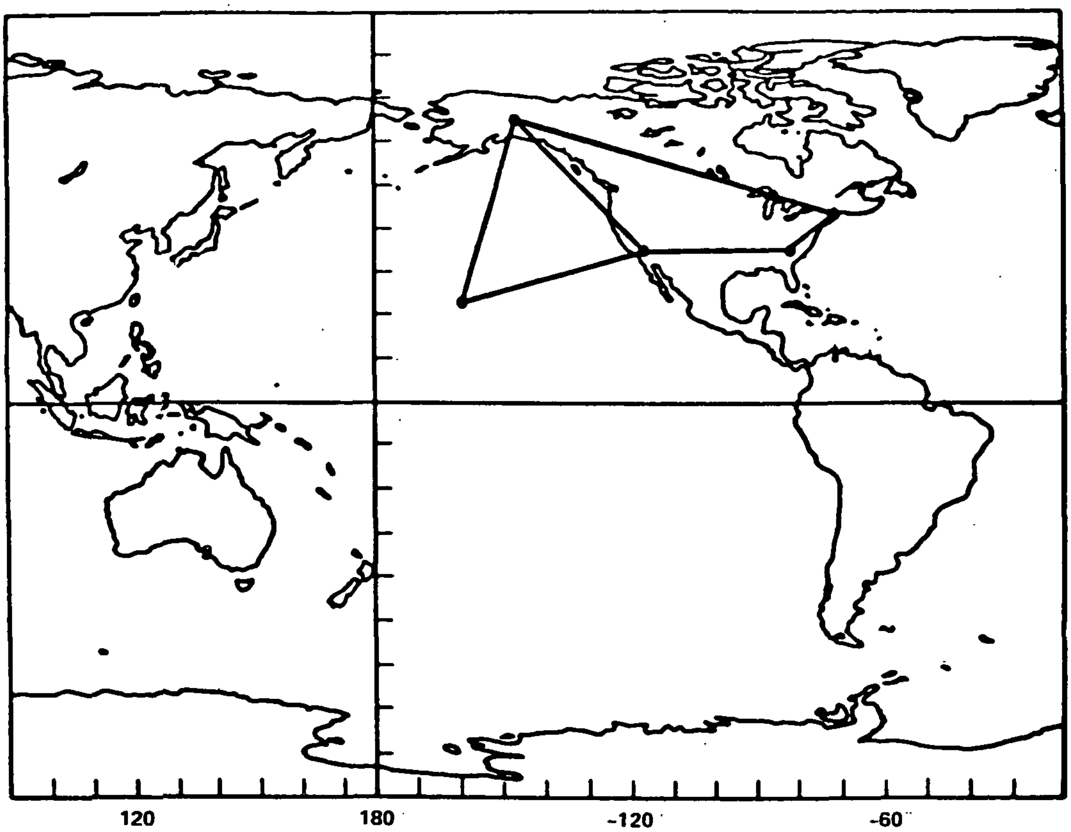

Figure IV-7. Pacific Plate Motion Experiment (PPME).

which lies to the north of that island (Figs. IV-8 and IV-9). The trough in the ocean surface is a manifestation of an anomaly in the earth's gravitational field in this area. This dramatic demonstration confirmed by direct observation the earlier indications of this striking feature which had been spot checked by tracking the GEOS-2 satellite from radar aboard the NASA tracking ship Vanguard as it traversed the trench. The radiometer and scatterometer, designed to measure wind speeds, also yielded valuable data which showed that they, too, can be expected to perform well in future EOPAP ocean dynamics missions.

Figure IV-10 shows Hurricane Ava as taken from the environmental satellite NOAA-2 on the left; on the right are graphs from Skylab S-193 showing radar scattering, radiometer temperature and, in the upper right-hand corner, wind speed. The peak wind of 45 knots (22 m/s) obtained from the scatterometer was observed some distance from the eyewall, which the sensor could not view because of look-angle constraints.

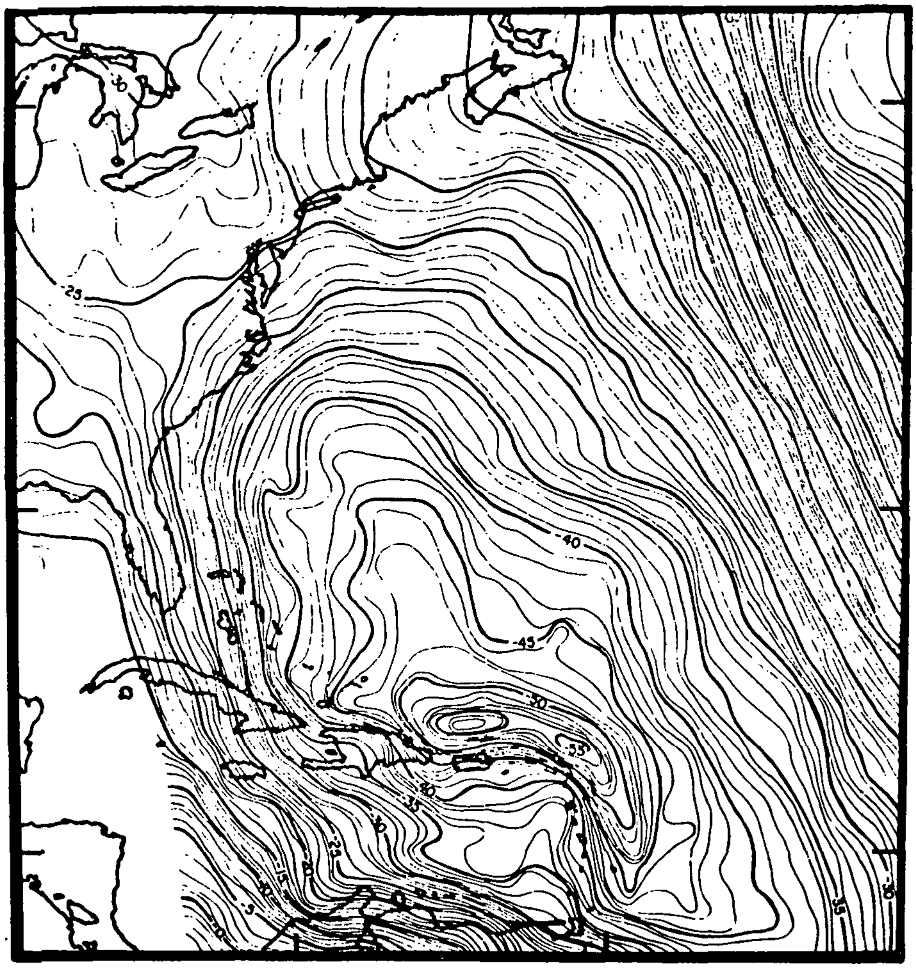

Figure IV-8. Geoid — the Western Atlantic — elevations (meters).

d. Flight Programs. The EOPAP includes two on-going flight programs, GEOS-C and LAGEOS, and a proposed new flight mission which is presently being considered by the Congress, SEASAT-A [13, 18, 19].

(1) The GEOS-C Mission. The next major step in the current program is the flight of an altimeter in GEOS-C to build upon the very successful proof-of-concept tests conducted during the Skylab Mission. The GEOS-C altimeter will map the sea surface topography over wide areas of the world's oceans. These findings are expected to yield a global picture of the geoid, which not only will be valuable as a key indicator of the structure of the tectonic plates which form the earth's cover but also will be important to the U.S. national defense posture. The wave height data to be obtained with these same instruments on a synoptic basis will permit development of better models of the air/sea interactions, which are vital elements in generating our global weather patterns.

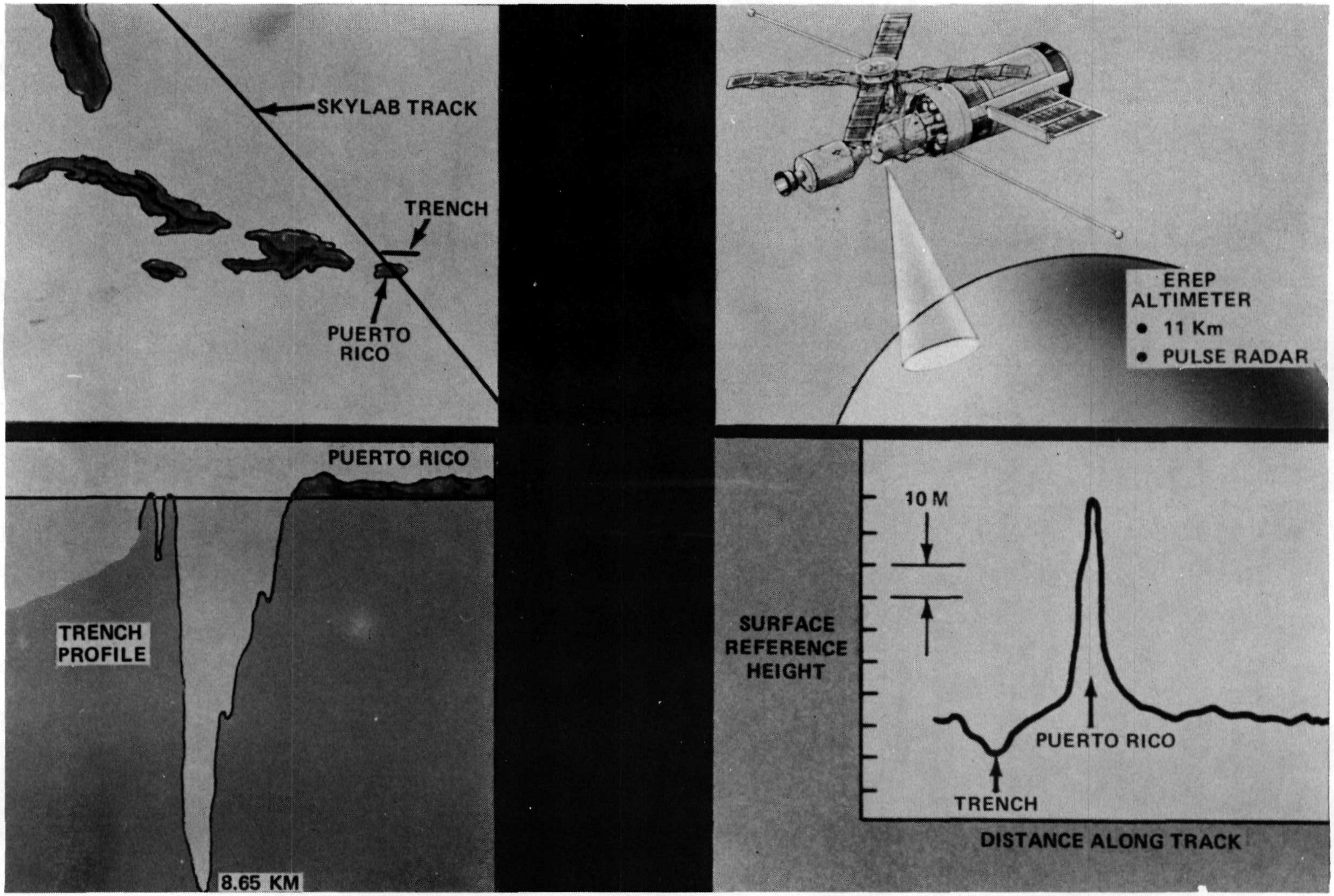

Figure IV-9. Geoidal studies of Puerto Rican trench.

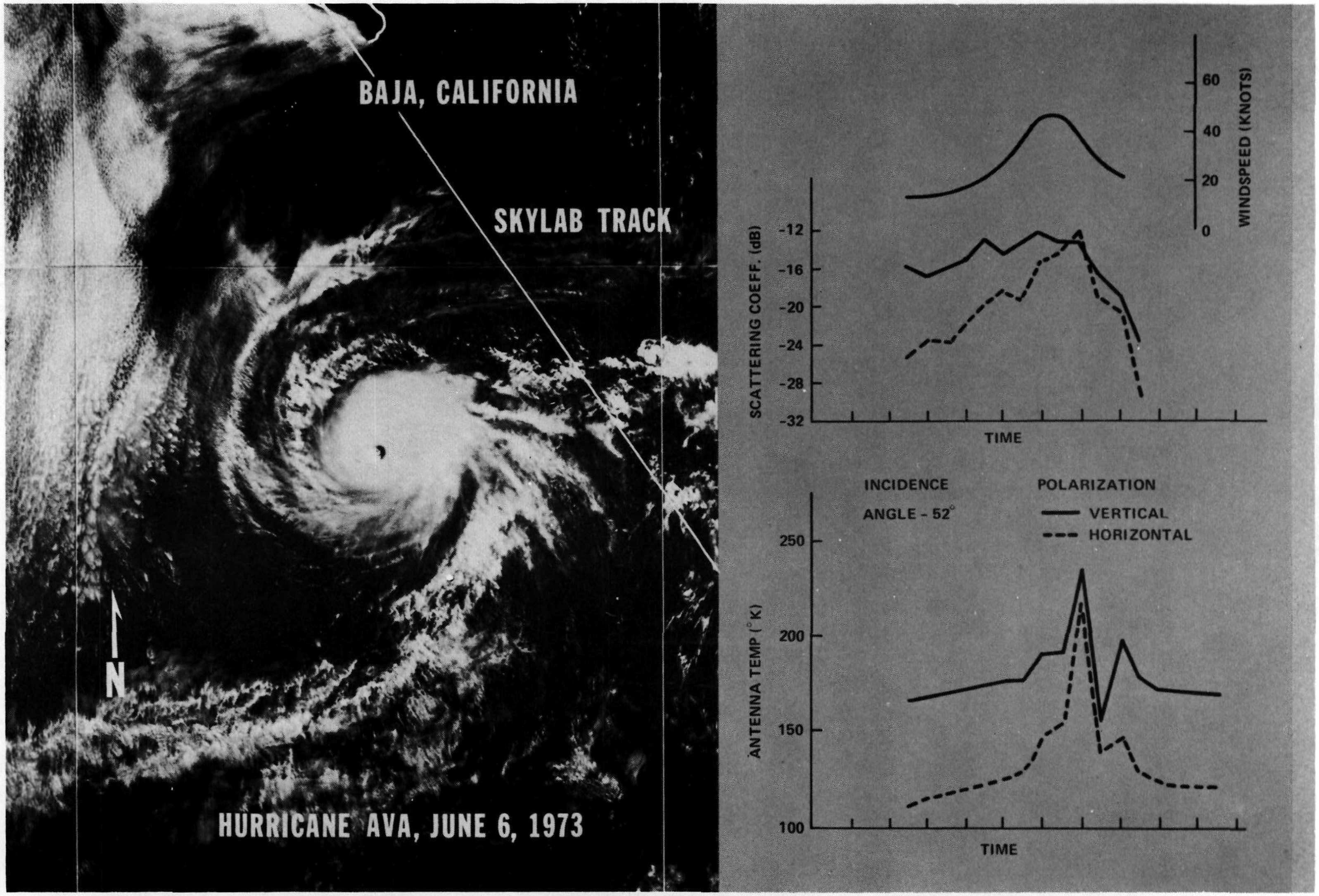

Figure IV-10. Hurricane Ava observations (June 6, 1973).

GEOS-C is scheduled for launch this year. It is being developed to demonstrate the technical feasibility of new systems and techniques to be used in the Earth and Ocean Physics Applications Program. The objectives of the GEOS-C Project are to demonstrate the feasibility of obtaining satellite altimeter measurements of the ocean topography, which will lead to a better understanding of ocean currents and tides, and to determine the capability of the altimeter to measure sea state, provide a more precise description of the earth's gravity field, improve the measurements of the variations of solid earth's geometry. An SST experiment conducted with ATS-F will demonstrate a new method for measurement of the earth's gravity field.

Spacecraft development, manufacturing and testing will be accomplished by the Applied Physics Laboratory of the Johns Hopkins University. Subsystem fabrication and testing are currently in process. The radar altimeter experiment is in the final stages of engineering model design verification testing, and fabrication of the protoflight and flight hardware is in process. The SST experiment hardware has completed design verification testing, and fabrication of flight hardware is in process.

Spacecraft integrated testing will start in the first part of CY-74 in preparation for shipment to the Western Test Range for launch later in 1974 by a two-stage Delta vehicle. The mission orbit parameters are:

Mean Altitude	843 km (500 n. mi.)
Inclination	115 degrees
Eccentricity	0.006 (maximum)
Orbit Period	101.8 minutes

Forty-one investigators, or investigator teams, were selected from the proposals that were submitted in response to a call for space flight investigations issued in October 1972. These teams are from government, university, and industrial organizations. Wallops Station, which has the project responsibility for GEOS-C, is in the process of negotiating contracts with the investigators.

Considerable activity has occurred in the mission planning area and a draft mission plan has been released by the project. Operational doctrines regarding spacecraft and experiment schedules, command requirements and sea surface observations have been formulated. The GEOS-C Mission Control

Center will be located at the Goddard Space Flight Center, with command and telemetry support provided through the existing tracking facilities. C-band tracking will be provided by selected DOD, NASA, and participating foreign stations. Doppler tracking will be accomplished via the Navy TRANET stations. Laser tracking will be provided by Goddard Space Flight Center and the Smithsonian Astrophysical Observatory laser stations; foreign participants are also being invited to join in the laser tracking. The SST experiment will be conducted utilizing ATS ground facilities and ATS-F satellite.

Both the DOD and the NOAA are providing operational support in the form of ocean surface monitoring, meteorology forecasts, etc., as well as funding support of the cost of the short pulse altimeter mode to meet their project objectives.

(2) The LAGEOS Mission. EOPAP requires a satellite range-measuring accuracy of 2 cm, in accordance with one of the principal recommendations of the Williamstown study: that NASA develop techniques for obtaining relative positions of points on the earth to that accuracy. A similar recommendation was made by the Space Science Board in 1971: that solid-earth physics "would require location accuracies on the order of ± 2 cm in a program lasting decades... ."

Range measurements with 2-cm accuracy will be used to accomplish many of the EOPAP objectives, such as the determination of plate tectonic motions, regional fault motions, the rotation and wobble of the earth, and earth-body tides. These objectives must be attained by measuring the variations with time of the internal geometry of a global matrix of fiducial points on the earth's surface, of the fiducial points with respect to the earth's center of mass, and of the matrix with respect to an inertial reference. These kinematic variations are known to have time scales ranging from a day, (e.g., body tides) to millenia (e.g., continental drift).

What is needed, then, is a means for making exceedingly accurate measurements on a global basis in such a way that, first, each position on the globe can be related to all others and to the earth's center of mass; second, complete sets of observations can be obtained in less than a day; and, third, continuity of observations is maintained over the longest possible time span. The first two considerations clearly suggest the use of a satellite in a high-inclination orbit; the third suggests that the satellite be passive. A satellite fitted with laser retroreflectors is an appropriate choice. The 1967-1968 National Academy of Sciences (NAS) summer study recommended that such a satellite be included in plans for the United States space effort (the NAS panel discussed this satellite under the heading GEDY-4) [20, 21].

A satellite that is optimum for EOPAP kinematic measurements should have the following characteristics:

(a) Such a satellite should have the maximum feasible mass-to-area ratio in order to reduce perturbations caused by nongravitational forces (mainly radiation pressure).

(b) The satellite should be compact and rigid for maximum stability of spacecraft geometry.

(c) It should be spherical so that the geometry of the retroreflector array versus the spacecraft center of mass will not change with aspect. The spherical shape is also necessary to minimize errors in computing corrections for radiation pressure and drag.

(d) A completely passive satellite is desirable in order to attain maximum operating life. The satellite will be acquired by camera (by photographing reflected sunlight against star background) and will be equipped with retroreflectors for ranging with ground-based lasers.

(e) The orbital altitude should be high enough to reduce to an acceptable level orbit errors resulting from uncertainties in geopotential models.

(f) Its orbital altitude should be low enough to provide good signal-to-noise ratios with a retroreflector array of reasonable dimensions.

(g) The inclination of the satellite should be high enough to provide global coverage.

(3) The SEASAT-A Mission. SEASAT-A is the first spacecraft dedicated to a partial meeting of the EOPAP objectives in ocean dynamics. It is an outgrowth of a diversity of scientific and technological work conducted by NASA, the Department of Defense, the Department of Commerce, and several other institutions in both the measurement of the required physical quantities and the implementation of the appropriate sensors on spacecraft and on the ground [22].

During the feasibility study phase of SEASAT-A, which took place in early 1973, NASA sought the involvement of the "user" community — the agencies and institutions that are the intended users of SEASAT-A data — to help insure that the needs of the organizations and the types and quantity of data to flow from the spacecraft are as satisfactory as possible. The list of active users is contained in Section 6.

SEASAT-A is a research-oriented program consisting of spacecraft, precision ground tracking systems, and data processing and modeling capabilities that will address both scientific and applications problems in ocean surface dynamics. Its strong suit is an array of active radar and passive microwave and infrared instruments that give it the capability of observing the ocean on a day/night, near-all-weather basis. It is this group of sensors that allows SEASAT-A to make quantitative measurements of oceanic, atmospheric, and geodetic parameters not only in clear weather but under wind and wave conditions, perhaps approaching hurricane force, as well as over regions lying under persistent cloud cover. A more detailed mission description is in the Appendicies volume.

(4) The GEOPAUSE Mission. The forthcoming 10-cm range tracking accuracy capability holds much promise in connection with a number of earth and ocean dynamics investigations. These include a set of earthquake-related studies of fault motions and the earth's tidal, polar and rotational motions, as well as studies of the gravity field and the sea surface topography which should furnish basic information about mass and heat flow in the oceans.

The state of the orbit analysis art is presently at about the 10-meter level, or about two orders of magnitude away from the 10-cm range accuracy capability expected in the next couple of years. The realization of a 10-cm orbit analysis capability awaits the solution of four kinds of problems, namely, those involving orbit determination and the lack of sufficient knowledge of tracking system biases, the gravity field, and tracking station locations.

The GEOPAUSE satellite system concept offers promising approaches in connection with all of these areas. A typical GEOPAUSE satellite orbit has a 14-hour period, a mean height of about 4.6 earth radii, and is nearly circular, polar, and normal to the ecliptic. At this height only a relatively few gravity terms have uncertainties corresponding to orbital perturbations above the decimeter level. The orbit is, in this sense, at the geopotential boundary; i.e., the geopause. The few remaining environmental quantities which may be significant can be determined by means of orbit analyses and accelerometers. The GEOPAUSE satellite system also provides the tracking geometery and coverage needed for determining the orbit, the tracking system biases, and the station locations. Studies indicate that the GEOPAUSE satellite, tracked with a 2-cm ranging system from nine NASA-affiliated sites, can yield decimeter station location accuracies. Five or more fundamental stations well distributed in longitude can view GEOPAUSE over the North Pole. This means not only that redundant data are available for determining tracking system biases, but also that both components of the polar motion can be observed

frequently. When tracking GEOPAUSE, the NASA sites become a two-hemisphere configuration which is ideal for a number of earth physics applications such as the observation of the polar motion with a time resolution of a fraction of a day.

GEOPAUSE also provides the basic capability for satellite-to-satellite tracking of drag-free satellites for mapping the gravity field and altimeter satellites for surveying the sea surface topography. GEOPAUSE tracking a coplanar, drag-free satellite for two months to 0.03 mm per second accuracy can yield the geoid over the entire earth to decimeter accuracy with 2.5 degrees spatial resolution. Two GEOPAUSE satellites tracking a coplanar altimeter satellite can then yield ocean surface heights above the geoid with 7 degrees spatial resolution every 2 weeks. These data will furnish basic boundary condition information about mass and heat flows in the oceans which are important in shaping weather and climate.

(5) The GRAVSAT Mission. The objective of the GRAVSAT mission is to determine the earth's gravity field and the geoid with a spatial resolution of 1 or 2 degrees and an uncertainty of the order of a decimeter in height.

This geoid will serve as a fundamental surface against which to refer the sea surface topography which is to be determined to an accuracy of the order of a decimeter by SEASAT-B and GEOPAUSE. The separation between the geoid and the sea surface topography provides an indication of the flux of the ocean currents. The gravity field information will also improve our understanding of the earth's crust. Gravity anomalies will, for example, reflect variations in densities, temperatures, and heat flow patterns and thus shed light on the existence and extent of convective cells which are thought to drive the tectonic plates.

(6) Magnetic Field Mapping Missions. Missions to map the earth's magnetic field are also being considered for the 1980's. It is anticipated that these missions will include spacecraft in high inclination, low altitude orbits for charting the total magnetic field on a global basis, as well as a satellite in a low inclination orbit at a higher altitude which will monitor magnetic effects associated with currents in the high atmosphere.

This latter information will be used to obtain the necessary corrections used in determining the magnetic field in the neighborhood of the earth's surface.

The Magnetic Field Mapping Missions are expected to yield data leading to better capabilities in connection with navigation and geophysical exploration for minerals and oil. The magnetic field information will be correlated with the gravity field data to furnish a more complete picture of crustal structure.

(7) Shuttle/Spacelab Missions. Advanced instruments for the earth and ocean dynamics programs of the 1980's will be tested in Shuttle/Spacelab flights. This mode of operation has already been previewed in the Skylab mission in which an altimeter, a radiometer, and a scatterometer were all tested in the proof-of-concept sense.

This actual in-orbit experience has been invaluable as we prepare for the flights of an altimeter in GEOS-C and a radiometer and a scatterometer as well as an altimeter in SEASAT-A. It is anticipated that instruments and systems which are more advanced and in some cases larger will be tested in this manner. These might include, for example, a multi-channel radiometer for ocean dynamics monitoring, and a spaceborne laser system for earth dynamics.

(8) Mini-LAGEOS Missions. The Shuttle will also provide a convenient means for piggyback launching of mini-LAGEOS spacecraft which will improve our knowledge of the gravity field and the earth's motions.

4. PROGRAM FUNDING

The funding of the EOPAP program is shown in Figure IV-11 and Table IV-1.

5. COST BENEFIT STUDIES

The benefits to be derived from the EOPAP fall into two classes: (1) protection of life and property, and (2) benefits whose potential economic value can be estimated in relatively quantitative terms. A number of the benefits expected from SEASAT-A are listed in Table IV-2.

A number of these specific benefit areas are being examined in detail to determine their economic potential as part of the SEASAT-A economic analysis which is now under way. The results of these detailed "case studies" of typical applications will provide the basis for the overall benefit assessment, the first phase of which will be completed this summer. Estimates of gains expected in other closely related activities will then be based on the results of these selected cases. Improved ship routing capabilities are, for example, expected to yield substantial economic benefits. Minimum-time routing of transoceanic shipping around storms and adverse currents can save 12 to 24 hours of ship time on a single crossing, which, when translated into savings at the rate of $10,000 a ship-day, amounts to eight figure numbers of dollars per year, worldwide. Reduced cargo breakage and insurance rates, and improved harbor and canal scheduling would add to those savings. Wave forecasts will also aid in scheduling of the critical process of deploying floating oil drilling platforms. Similarly, measurements of wave spectra on the continental shelves under storm conditions are necessary for the location and design of offshore structures such as floating nuclear power plants and deep water oil ports.

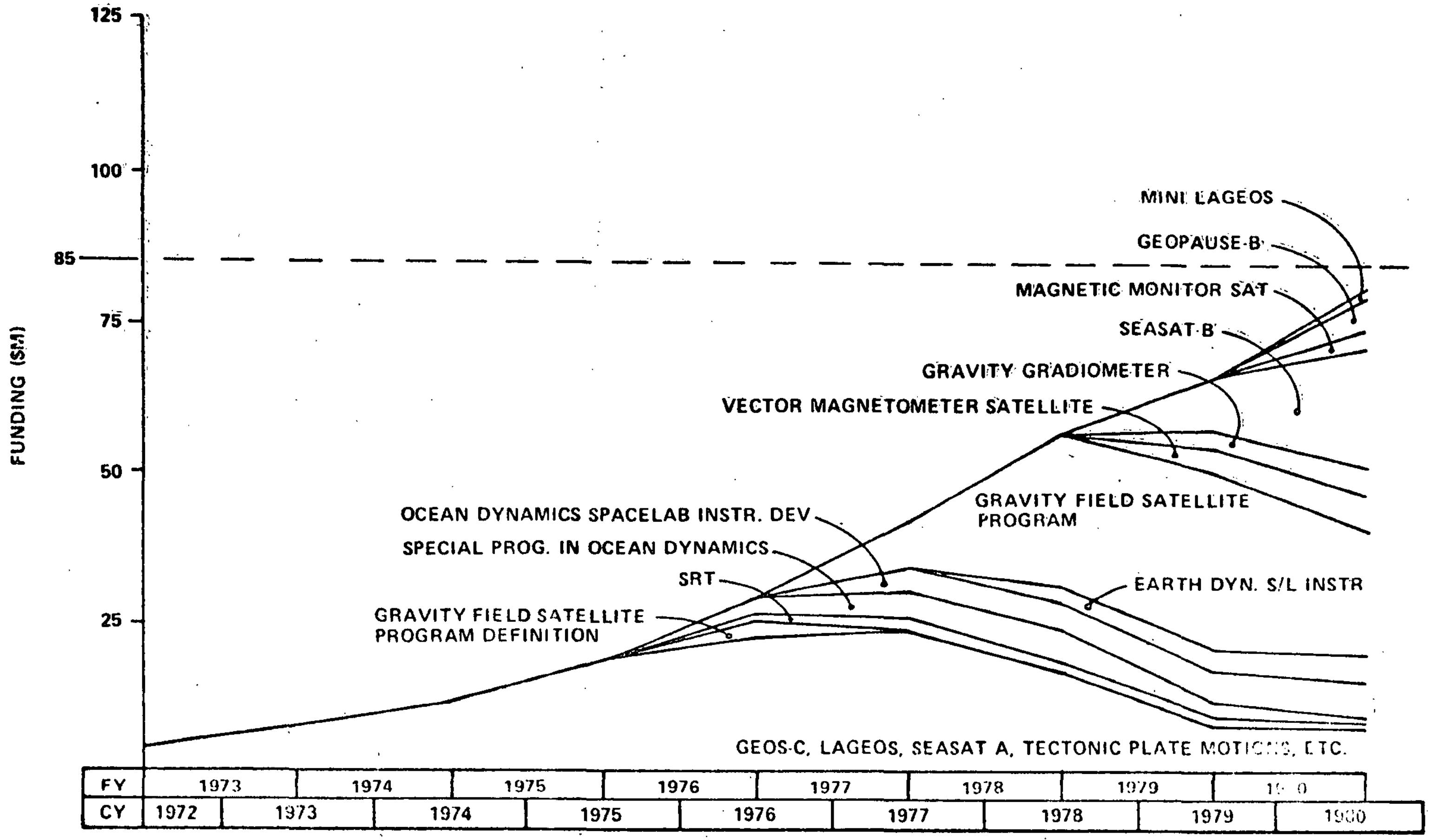

Figure IV-11. EOPAP funding trend.

TABLE IV-1. EARTH AND OCEAN PHYSICS APPLICATIONS PROGRAM FUNDING

Program Element	Fiscal Year Funding ($M)			
	1972	1973	1974	1975
Geodetic Satellites (GEOS-1 and -2)	1.2	1.1		
Geodynamic Experimental Ocean Satellite (GEOS-C)	3.1	4.2	3.4	0.9
Laser Geodynamic Satellite (LAGEOS)			1.3	2.3
Ocean Dynamics Satellite (SEASAT-A)				8.0
Tectonic Plate Motion				2.0
Experiment Data Analysis			2.7	2.7
Measuring System Forecasting Technology and Modeling		2.2	3.0	2.6
Total	4.3	7.5	10.4	18.5

6. INSTITUTIONAL ARRANGEMENTS

Institutional arrangements developed in connection with EOPAP are complex. Looking toward the user community, NASA works in the first instance with other government agencies, such as NOAA and DOD in the ocean dynamics area and the USGS in the earth dynamics area.

Coordination of NASA's activities with those of the Departments of Defense and Commerce is effected through the Geodetic Satellite Policy Board.

The principal user agencies, in turn, will work much more effectively with their own well-developed communities of users when the new data generated by space techniques become available.

TABLE IV-2. USER BENEFITS

- Improvements in Information Services
  - More Accurate, Long Term Environmental Forecasting
  - Improved Warning of Storms and Surges
  - Prediction of High Seas and Adverse Currents
  - Ice Field Mapping and Monitoring
- Maritime Operations
  - Optimum Ship Routing and Scheduling
  - Improved Ocean Exploration Operations Planning
  - Improved Design and Siting of Offshore Structures
  - Improved Ship Design
  - Improvement in Shoreline Operations
- Utilization of Ocean Resources
  - Facilitate Exploration for Oil and Mineral Deposits
  - Identification of Areas of High Biological Productivity

The structure and operating practices of the multilevel user community in the ocean dynamics area is a good case in point. The new ability to determine and predict ocean surface conditions in terms of wave directional spectra will, for example, permit NOAA and DOD to add this kind of information to the data they now supply, which is currently based to a large extent on meteorological forecasts. The wave prediction data and the improved weather forecasts made possible by data of the type to flow from SEASAT will be disseminated to the "ultimate" users, the ship operators and masters, in the same way that weather forecasts and ship routing recommendations are currently furnished. This is done either directly by DOD or by commercial concerns which use weather forecasts to generate the ship routes which they furnish to shippers. Similar situations occur in other areas.

The list of major active users for SEASAT-A is large. From the Federal Government, it includes:

Department of Commerce
- National Oceanic and Atmospheric Administration
- Maritime Administration

Department of Defense
- Defense Mapping Agency
- Army Corps of Engineers

Navy Weather Service Command
Office of Naval Research
Naval Weapons Laboratory
Naval Research Laboratory
Naval Oceanographic Office

Department of Interior
Geological Survey

Department of Transportation
Coast Guard

Atomic Energy Commission

Environmental Protection Agency

National Science Foundation

National Aeronautics and Space Administration

National Academy of Sciences

National Academy of Engineering

Institutional users who are active participants are:

Smithsonian Institution Astrophysical Observatory

Woods Hole Oceanographic Institution

Scripps Institution of Oceanography/University of California

University Institute of Oceanography/City College of New York

Battelle Institute

From the private sector, the user community includes:

American Institute of Merchant Shipping

American Petroleum Institute

Sea Use Council

New knowledge of earthquake mechanisms will be employed by agencies such as USGS and the National Science Foundation to develop approaches to the earthquake prediction problem. User agencies such as USGS will then, together with other appropriate government agencies, approach the problem of utilizing this new kind of capability.

7. REFERENCES

1. 1968 Summer Study Report.

2. Solid Earth and Ocean Physics, Report of a Study at Williamstown, Mass. to NASA, 1969.

3. NASA Earth and Ocean Physics Applications Program Plan, Sept. 1972.

4. Siry, J.W.: A Geopause Satellite System Concept. Space Science Reviews, vol. 14, no. 2, pp. 314-341.

5. Siry, J.W.: Crustal Motion Measurement by Means of Satellite Techniques. Goddard Space Flight Center Report No. X-590-73-273, May 1973. Presented at the AGU Third GEOP Research Conference, May 31 and June 1, 1973.

6. Proceedings of Space Shuttle Sortie Workshop, July 1972.

7. Space Shuttle Payload Planning Working Groups Final Report, May 1973.

8. Jet Propulsion Laboratory: Earth Physics Satellite, Gravity Gradiometer Study. Report No. 760-70, May 17, 1972.

9. Chovitz, B.; Lucas, J.; and Morrison, F.: Gravity Gradients of Satellite Altitudes. NOAA Technical Report No. NOS 59, Nov. 1973.

10. Siry, J. W.; Kahn, W. D.; Brayn, J. W.; and Vonbun, F. O.: Gravity Model Improvement Investigation. GSFC Report No. X-590-73-249, Jan. 1973.

11. EOPAP Congressional Testimony, FY 1975.

12. EOPAP Ocean Dynamics Program, Mar. 1974.

13. SEASAT Program Plan, Apr. 18, 1974.

14. SEASAT-A Congressional Testimony, FY 1975.

15. Research and Technology Operating Plan Summary, NASA, Fiscal Year 1973.

16. Advanced Applications Flight Experiments (AAFE) Announcement of Opportunity, AO2, NASA, Mar. 25, 1974.

17. Skylab Earth Resources Investigations, NASA, OMSF/OA, Feb. 1973.

18. LAGEOS Project Plan, Feb. 1974.

19. GEOS-C Project Plan, Aug. 1973.

20. Weiffenbach, G. C.: Use of a Passive Stable Satellite for Earth-Physics Applications. Smithsonian Astrophysical Observatory, Apr. 1973.

21. Siry, J.W.: The LAGEOS System. NASA, Mar. 1974.

22. SEASAT-A Task Team Report, Oct. 1973.

An extensive bibliography may be found in the Appendix volume.

CHAPTER V. COMMUNICATIONS AND NAVIGATION

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

CHAPTER V. COMMUNICATIONS AND NAVIGATION

The communications and navigation (C&N) space program has relied on expendable launch vehicles to carry satellites into space. This method of transportation has required that the satellite's size and weight be compatible with a particular launch vehicle. However, in some cases the vehicle could not support the desired spacecraft mission. Therefore, because a large cost increment would have been necessary in order to use the next larger launch vehicle, occasional compromises in spacecraft capability that limited the payload to more moderate mission goals were at times necessary.

It is expected that a nonexpendable, manned launch vehicle, the Space Shuttle, will be operational in the early 1980's. It will be able to carry satellites into low earth orbit where they will be released, and if necessary, placed into the desired orbit. With a maximum payload lift-off weight of 30,000 kg, the Space Shuttle can place one large and/or a number of small size, standardized spacecraft into desired orbits.

1. HISTORY

The era of active communication satellites began in December 1958 with the Army Signal Corps' Project Score. A prerecorded Christmas message by President Eisenhower was transmitted to earth at 132 kHz from the satellite for 12 days, until its batteries failed, thereby proving that the active satellite technique was feasible. Although very limited in capability, it was nevertheless successful in proving the concept.

The Army's Courier communication system, a follow-on of Project Score, was a two-way, delayed repeater system which received a message from one ground station, stored it, and then on command from another station transmitted the recorded message to earth. Courier demonstrated that it was possible to orbit an active repeater satellite capable of handling a large message flow (about 340,000 words in a 5 minute period).

NASA's communication satellite flight activities began with the launch of Echo 1 on August 1960. NASA developed and launched eight communication research satellites in the Echo, Relay, and Syncom programs. These research flights were supplemented by two Telstar satellites developed by the American Telephone & Telegraph Co. and launched by NASA for reimbursable costs.

Experiments with passive communication satellites were conducted with Echos 1 and 2. From a technical point of view, Project Echo showed that it is possible to communicate between widely separated points on the globe by bouncing radio signals off passive reflectors. Echo 1 was a 30-meter-diameter balloon constructed of Mylar and coated with aluminum. It was self-inflated after being placed in a low earth orbit, about 1600 km high. The first real-time transmission via satellite was conducted with Echo 1 from Bell Telephone Laboratories in New Jersey to Paris, France, in 1960.

Echo 2, a somewhat larger, more rigid balloon than Echo 1, was launched in January 1964. It self-inflated to become a sphere 41 meters in diameter. Voice and teletype communication tests were conducted with it between England and the U.S. The launch of Echo 2 concluded NASA's experimentation with passive communication satellites. The early successes of the more promising active-repeater communication satellites made additional NASA research with passive balloons unnecessary.

Telstar 1, designed and constructed by A.T.&T., was launched on July 10, 1962, into a medium-altitude (5600 km high) orbit. It was the world's first active-repeater communication satellite, designed to receive signals from the ground at 6390 MHz and retransmit at 4170 MHz. Telstar conducted numerous telephone voice communication tests between the U.S. and France and England.

Relay 1 was NASA's first entry into the active-repeater communication satellite field. Launched in December 1962 into a medium altitude orbit of 7500 km apogee (farthest point from the earth) and 1300 km perigee (nearest point to earth), it was covered with solar cells to provide 50 watts of power. Tests of 12-channel telephone, wideband (TV) transmission, and data transmission were conducted with Relay 1 to determine the technical limitations of this type of communication link and to optimize its efficiency.

Telstar 2 and Relay 2, launched in May 1963 and January 1964, respectively, were used to demonstrate transoceanic, wideband communication experiments.

On July 26, 1963, Syncom 2 was launched into a circular orbit 36,000 km over the Atlantic Ocean and became the world's first successful synchronous spacecraft. (Synchronous spacecraft orbit at the same speed as the earth, but not necessarily in the plane of the equator.) Syncom 2 was stationed above Brazil (a satellite's "station" is the portion of the earth it serves). Since its orbit was inclined 33 degrees to the equator, Syncom 2 moved in a figure-8

pattern bounded by 33 degrees north and south of the equatorial plane. This meant that, while Syncom 2 was always visible to ground stations on the east coast and thus always available for communications experiments (unlike low orbit satellites which pass in and out of view), it would rise and fall in the sky and thus required relatively complex ground antenna tracking systems to follow its path. However, those stations in the fringe areas of the satellite's view (either northernmost or southernmost) would pass in and out of view as the satellite moved.

Syncom 3 was launched into synchronous orbit on August 19, 1964. A complex series of space maneuvers never before attempted placed the satellite in a true equatorial-plane orbit at such an altitude (36,000 km) that it appeared to be stationary above the earth. This type of orbit, known as geostationary, is desirable for continual communication from one part of the globe to another. Because the satellite remains above one location, there is no gap in communication services. Syncom 3 successfully performed a variety of communications tests, including television relay of the 1964 Olympic Games in Tokyo to the United States, the first TV program ever to span the Pacific.

The success of the Syncom project demonstrated the feasibility of the geostationary mode of satellite communications. This key development led to the abandonment of the more complex and more expensive medium-altitude, random-orbit system pioneered by Telstar and Relay and opened the door to the simpler, more reliable, less costly commercial system subsequently installed by the Communications Satellite Corporation (COMSAT). The random-orbit system is more complex and expensive than a system using a geosynchronous satellite for two reasons: (1) In order to provide 24-hour coverage, a random-orbit system needs a large number of satellites for continuous service, so that at least one satellite is always within communications range of a given ground station, and (2) since the random-orbit satellite's position relative to a given point on earth is continually changing, the ground transmitting and receiving stations must be more complex than they need to be for a geostationary satellite system, which needs only one stationary antenna at each receiving station. The random-orbit satellite system demands at least two antennas at each station so that as one satellite is passing out of the range of one antenna, a second antenna can begin to send signals to or receive signals from the next satellite coming into range. In addition, each antenna must be capable of following a satellite as it moves across the sky.

The syncom project demonstrated that satellites were useful for transmitting voices, narrow-band television images, and data over long distances. Likewise, the establishment of the International Telecommunications Satellite

Organization (INTELSAT) demonstrated that the necessary operational organizations were available to handle commercial communication satellites. Therefore, in 1964 NASA introduced the Applications Technology Satellite (ATS) Program to investigate and flight test technology experiments in space applications and spacecraft, including communications as well as navigation and meteorology.

One of the important contributions of the ATS-1 and -3 geostationary missions was the proving of the technology necessary to permit the radio frequency transmission power to be confined to a cone-shaped beam covering only the earth's disk, with no wasted energy transmitted to space. This improvement can be directly converted either into a reduction in satellite launch weight (and thus cost) or, more important, into a substantial reduction in the ground receiving and transmitting station costs.

The first satellite in the ATS series, launched on December 6, 1966, was geostationary. Its antenna, which produced a cone-shaped beam, increased power utilization over previous satellites by a factor of at least 10. ATS was placed on station at 151 degrees west longitude in the equatorial plane and has been maintained there ever since. The ATS-1, with a design lifetime of 1 year, has been operating for 8 years. ATS-1 (as well as ATS-3 and -5, to be discussed later) is a multi-mission/multi-experiment satellite, with a heavy emphasis on communications: higher power, different frequencies [very high frequency (VHF) for aircraft and ships, superhigh frequency (SHF) for television and other communications], and larger ground stations. ATS-1, -3, and -5 also included experiments in science, meteorology, and space technology.

ATS-2, launched in April 1967, failed to achieve proper orbit.

ATS-3 was launched on November 5, 1967. From its station of 47 degrees west longitude, the satellite could be used to watch hurricane buildup and could be used by European ground stations. In November 1967, the satellite station was temporarily changed to 95 degrees west longitude in the equatorial plane to permit better observation of the central United States during the tornado season. ATS-3, like ATS-1, had a design lifetime of 1 year but is still operating.

Both ATS-1 and ATS-3 carry VHF communication transponders (receivers, amplifiers, and transmitters) for experiments in ground-to-mobile communications via satellite. The transponder on ATS-3 is a refinement of the one on ATS-1, providing a capability for multiple access which the former does

not have. Multiple access refers to a multi-channel capacity in which several independent, two-way transmissions from different pairs of ground stations can use a single transponder; thus each two-way transmission does not need its own separate transponder.

ATS-4, launched in August 1968, failed to achieve proper orbit.

ATS-5, the last satellite in the initial ATS program, was launched on August 12, 1969. This satellite used a stabilization system different from that used on the ATS-1 and -3. However, problems with the ATS-5 stabilization system occurred not long after launch, and therefore the experimental program has been limited.

Since mid-1969, NASA has made the communications channels of ATS-1, -3, and -5 available to the user community for applications experiments. Diverse organizations, such as the Corporation for Public Broadcasting, Atomic Energy Commission, Federal Aviation Administration, Maritime Administration, Duke University Medical Center, Netherlands Coast Guard, UK Board of Trade, and Royal Norwegian Council for Scientific and Industrial Research, have used the limited channel capacity of these satellites for a wide range of experiments, including transcontinental transmission of television programs, position-location of trucks on the highways, communication with and and position-location of aircraft and ships in transit, radiographic and fluoroscopic image transmission, and data collection from ocean buoys. Of particular interest are the experiments listed below.

- The State of Alaska and the Department of Health, Education, and Welfare have conducted a tele-medicine communications experiment with the ATS-1 satellite to determine the role and value of communication satellites in providing reliable, narrow band, long-distance communications to isolated communities. The narrow band (voice bandwidth) precludes television picture transmission. A typical use of the voice channel is the village medical aide's calling a doctor at a field service hospital or a city medical center to describe a patient's symptoms and receive advice on treatment. If evacuation is required for treatment in a hospital, the degree of urgency can be discussed and a bush plane can be ordered when necessary.

- A program of consultation for medical aides was also conducted by the National Institutes of Health (NIH) in cooperation with the University of Washington, Stanford University, and the University of Wisconsin. The University of Washington still continues teleconsultation and transfer of medical record data, diagnostic data, and research materials among the Field Service Hospitals.

- Ground station terminals have been established and experiments have begun at the University of Hawaii, the University of the South Pacific in Fiji, and the Polytechnic Institute of Wellington, New Zealand. To date, the network has experimented with voice and facsimile transmissions and slow-scan television and teletype experiments. A highly successful experiment is the facsimile transmission of pages of library books between campuses. Prior to the availability of the ATS facsimile channel, copies of pages were delivered to the libraries by ship-carried mail, a much slower process. The satellite facsimile distribution service can also provide more equitable distribution of scarce library materials than can present systems, because it provides an inexpensive (to the user), rapid method of transferring information. Other experiments have included sharing classes and seminars with classes in remote areas, which participate by satellite link.

These experiments are part of a process necessary to establish the applicability and cost-effectiveness of satellite communications. Once established, the user benefits could be substantial.

2. GOALS AND OBJECTIVES

Two statutes constitute NASA's charter in the space communications and navigation area. One is the Space Act of 1958, which says in part:

> The United States policy should be devoted to peaceful purposes for the benefit of all mankind. Space activities should contribute materially to improvement of aeronautical and space vehicles, potential benefits to be gained from aeronautical and space activities for peaceful and scientific purposes, the preservation of the role of the United States as a leader, and cooperation with other nations [1].

The other statute is the Communications Satellite Act of 1962, which stipulates in part that NASA shall advise the Federal Communications Commission (FCC) on technical characteristics of the communications satellite system; cooperate with COMSAT in research and development to the extent deemed appropriate by the Administration in the public interest; and provide, on a reimbursable basis, other services to COMSAT [2].

NASA's Communication Program objectives were aptly stated by the Space Task Group report to the President [3] and by the NASA report to the Space Task Group [4]:

- Communications: To facilitate the application of satellite and space technology to communication needs, nationally and internationally, and to the need for data collection from earthborne, airborne, and spaceborne vehicles.

- Navigation and Traffic Control: To facilitate the application of satellite systems and space technology for the improvement of terrestrial, air, and space vehicle navigation, and traffic control.

To satisfy these requirements, each new planned activity begins with an investigation of the needs for new services and with an assessment of the applicability of satellites to this need, since it is not always obvious that a need is best satisfied by the use of a satellite. In fact, one of NASA's most important responsibilities is to ensure that, in each case, the relative merits of satellites and other means of obtaining similar results are thoroughly investigated.

Where it is clear that the satellite approach is appropriate, NASA must develop the critical technology, flight-test it, and at the same time, with the competence thus developed, provide technical consultation to other government agencies.

These steps were followed in planning the two current communication satellite programs, the ATS-F and the joint U.S.-Canadian Communication Technology Satellite (CTS). These programs will be discussed in detail in Section 3.

In 1967-1968, the National Academy of Sciences (NAS) was asked by NASA to conduct a study of the useful applications of earth-oriented satellites. The study had as its objectives an examination of the probable future usefulness of satellites in practical earth-oriented applications and a consideration of the economic factors. Of the 11 technically-oriented applications discipline panels formed by NAS, 4 were germane to the C&N area: broadcasting, points-to-point communications (data collection employing small terminals), point-to-point communications, and navigation and traffic control. The results and recommendations of the study are presented in References 5 and 6. NASA has endeavored to meet the recommendations presented by the Central Review Committee [5] and it is believed that a majority of those related to C&N have been accomplished, either by government agencies or private communications companies.

Since January 1973, NASA has refocused its satellite communication objectives and research and development (R&D) efforts toward meeting longer term national needs, as well as meeting its own space telecommunications needs. This decision was made because it was believed that further advances in near-term satellite communications R&D could be accomplished by industry from its own finances without Federal Government support. Therefore, NASA announced a phaseout of all new satellite flight research activities in communication satellite research and development. Nevertheless, R&D support by NASA was still required so that technical consultation and support services to other agencies of the government in satellite communications could continue.

The refocusing of NASA's satellite communications program objectives did not eliminate the ATS-F and CTS programs. The development of ATS-F will continue toward a planned launch in June 1974, and the cooperative development of the CTS with Canada will also be continued. In addition, NASA will continue: (1) to develop the technology required to communicate to and from NASA satellites and to meet its statutory responsibilities under the Space and COMSAT Acts; (2) to provide technical support to the Department of Transportation (DOT) — its Federal Aviation Administration (FAA) and U.S. Coast Guard — and the Department of Commerce's (DOC) Maritime Administration in planning aeronautical and maritime communications and position-location experiments of interest to them; (3) to support the FAA in Collision Avoidance System time dissemination experiments; and (4) to support Atomic Energy Commission (AEC) experiments in communicating via satellites from their trucks carrying nuclear materials to a central AEC receiving station.

3. IMPLEMENTATION

a. <u>Introduction</u>. In order to fulfill the objectives discussed in the preceding section (i.e., determine the applicability of satellites to future communication and navigation needs, provide R&D in C&N satellite technology, and support other agencies in their C&N satellite programs), NASA's C&N satellite program must be concerned with at least three areas: completion of current flight missions which will provide much of the necessary technical and applications information; the data collection system which will collect and disseminate the information gathered by the remote sensors; and the applications of the existing and newly developed satellite communication services.

b. <u>Missions</u>

(1) Applications Technology Satellite (ATS-F) [7]. In late 1964, NASA studied the user community's future needs for telecommunications services and the communication spacecraft technology that should be developed

and demonstrated. One of the conclusions of the study was that if community services (e.g., medicine, library, health, education) to remote and widely distributed populations were to become economical, space communication systems which could work with hundreds to thousands of low-cost ground systems needed to be developed. In order for a communication system to utilize small, inexpensive ground antennas which could receive high quality television signals, future spacecraft would have to provide much greater signal intensity at the ground receiving stations than was currently possible. Therefore, the future spacecraft would have to possess a relatively large directive antenna and much greater stabilization accuracy than had been possible with previous spacecraft. These findings were used in the development of the ATS-F.

The study showed that, because of technical constraints, the largest feasible size for a spacecraft antenna was 9.15 meters. This was, however, large enough to meet the requirements of a fairly economical communication system using inexpensive, small ground receivers. The 9.15-meter, directive antenna's narrow beam is capable of radiating to selected portions of earth and represents an improvement over previous antennas which could only direct beams to the earth's disk. In addition, the requirement for a greater degree of stabilization than on previous spacecraft was met by providing a stabilization system having an accuracy of 0.1 degree. The ATS-F, scheduled to be launched in June 1974, will test this improved satellite system.

It will carry out the following communications and navigation experiments with user organizations:

- The Health/Education Telecommunications (HET) experiment, in conjunction with the Department of Health, Education and Welfare, will test the application of satellite communications to education and two-way medical teleconferencing. This experiment is a multi-region effort which involves the Federation of Rocky Mountain States, Appalachian Regional Commission, Veterans Administration, Regionalized Medical School, and the State of Alaska [8]. It requires the installation of about 130 receivers procured from industry, each costing about $3,700.

The experiment will be conducted in a new frequency band (2.5 to 2.69 GHz), somewhat below the band authorized for commercial, point-to-point communications (6/4 GHz). This new band is authorized for broadcasting rather than point-to-point service and thus is appropriate for an experiment such as HET. However, strength of the signal arriving on the ground is limited by regulations to preclude interference with existing terrestrial services, thereby inherently limiting the degree to which the ground receiving stations can be made smaller and thus less expensive.

- The Satellite Instructional Television Experiment (SITE), in conjunction with the Indian Government, will test the applicability of satellites to broadcasting TV programs, both educational and entertainment, to remote areas which cannot usually receive such broadcasts. About 5,000 Indian villages will be included in the experiment. Some of the villages will have community receivers for direct reception from the ATS-F broadcasts [9].

- The Position Location and Communication Experiment (PLACE), in conjunction with DOT and DOC, will test real-time communications among central ground stations, evaluate communications between airplanes and ships using a satellite, and determine the position accuracy possible at the L-band frequency using ranging techniques [10].

Equipment incorporated in the ATS-F will permit measurement of the atmospheric effects on radio frequencies which are of interest to future satellite communications (the bands of 13, 18, 20, and 30 GHz) and will permit measurement of surface-generated interference to the currently employed uplink frequency of 6 GHz.

(2) Communications Technology Satellite (CTS) [11]. To provide an increased capability for regional or national broadcast and information network satellite services with inexpensive ground stations, new frequency bands without power limitations must be used. Therefore, in April 1972 the Canadian Department of Communications and NASA agreed to the joint development of an experimental satellite to pioneer in the use of the newly allocated 11.7 to 12.2 GHz frequency band for satellite broadcasting to smaller, less expensive ground terminals than those now used by COMSAT. This band was allocated for commercial communications and broadcasting, to be shared equally, but without restrictions on the amount of power transmitted. In addition to the lack of restrictions on transmitted power, enough bandwidth was authorized to carry many television channels, much more than at the lower (6/4 GHz) frequencies. The CTS will be the first satllite to use these new bands and will make important contributions toward developing the capability for broadcast and information network services to relatively small earth terminals. Extensive communications experimentation will be required to develop and prove the equipment required for these new frequencies and to resolve uncertainty associated with broadcasting through heavy rainfall at the higher frequency. The satellite will also permit user communication tests in education and medical material transfer. Launch into a geostationary orbit is planned for late 1975.

A CTS users' guide has been prepared to assist prospective U.S. investigators in utilizing the 50 percent experiment time available to the U.S. [12]. Nine experiments associated with education, health care, document delivery,

disaster communications, and propagation phenomena have been conditionally accepted. The Canadians are also selecting experiments from among 45 proposals submitted to them. A description of the U.S.-CTS experiments is contained in Reference 13.

c. Data Collection. Data collection by satellite is defined as the recovery of information from remote data-gathering stations (such as oceanographic buoys and ships, automatic meteorological and hydrological stations, weather balloons, research aircraft, etc.) and its transmission to appropriately located central data-handling centers where it is used or disseminated to the user.

Data Collection Systems (DCS's) include the user's platform telecommunications subsystem and associated scientific sensors; the satellite relay, whether it be in a geostationary or low-altitude orbit; the ground receiving subsystem to obtain the information directly from the user platform or via the satellite; and the data processing and dissemination subsystem.

Satellite usage for collecting and transmitting data from large numbers of simple and unsophisticated platforms was first introduced into the NASA program to aid meteorologists in measuring in-situ wind velocity, air temperature, and air pressure using free-drifting balloons. Nimbus-3 and -5, ATS-3, and the Cooperative Applications Satellite 1 (CAS-1) were carriers of space telecommunications equipment capable of receiving signals from and transmitting signals to moving instrumented balloons. These satellite experiments, called Interrogation, Recording, and Locating Subsystem (IRLS), Omega Position Location Experiment (OPLE), and French Meteorological Satellite (EOLE), respectively, were highly successful in position-locating the balloons and receiving the onboard sensor data.

In addition to the above-mentioned space experiments, numerous studies related to data collection systems have been performed by NASA, industry, and NAS [14,15]. During the NAS Space Applications Summer Study in 1968, the Panel on Points-to-Point Communications, in referring to data collection, recommended that [15]:

> Because 60 percent or more of the globally distributed, small data platforms expected for 1975 are currently in place and operating; because only restricted synoptic, real-time data-collection service now exists; and because the hypothetical Data Collection Relay Satellite (DCRS) system for providing this needed service has been estimated to be cost-effective, the

Panel recommends that development, acquisition, and operational deployment of this type of system be planned and supported. As first steps, detailed studies should be conducted to define the traffic in more detail and to develop standard specifications for the data-platform electronics.

The Panel estimated that there would be potentially 26,180 platforms (balloons, buoys), representing 18 different classes of use/disciplines (agriculture/forestry, etc.) that might be operational in the 1970's. The major traffic requirement would probably be "that of position-location or horizontal-sounding balloons" [15] which would be used primarily in meteorological and pollution monitorong systems.

NASA must determine from past and future studies who the prospective users are for data collection services that utilize satellites. This determination should also reveal the numbers and approximate geographical distribution of platforms which the users will require and can financially support over a period of time.

d. Applications

(1) Introduction. Looking ahead to the 1980's and the 1990's, NASA foresees a greatly increased demand for existing and new satellite communication services, such as international and domestic telephone, TV and data message traffic, aeronautical and maritime communications and position location, broadcasting to small fixed terminals, and data collection employing thousands of small terrestrial telecommunications units. The ATS-F, previously mentioned as providing health, educational, and instructional television experimentation, is expected to stimulate the demand for new operational satellite services. Library material transfer and the use of communication satellites for postal data transfer (electronic mail services) are also potential future space applications.

(2) Orbit and Frequency Use. For the applications of satellite communications to grow in the future, two constraining factors must be taken into consideration. The first is that the number of geostationary satellites which can be used is not infinite because there are a limited number of orbit positions available. The second is that the radio frequency spectrum allocated to communication satellites is also limited; at the present, this spectrum is below 10 GHz, except for the newly allocated higher bands for the CTS and ATS-F, mentioned previously. Therefore, technical information on these parameters needs to be developed. NASA is now providing such technical information to

the FCC and Office of Telecommunications Policy (OTP) in an attempt to reduce the possibility of interference between satellite communication systems.

In addition, NASA needs this technical information for its ongoing space program. NASA is particularly interested in reducing the radio interference which has been experienced at an increasing rate by in-orbit satellites. There are two thrusts to NASA's R&D in this area of communication satellites. The first is to find better methods of using the existing below-10-GHz spectrum. This involves finding ways of sharing the existing frequencies while minimizing interference. The second thrust is to open up frequencies above 10 GHz to alleviate radio frequency crowding.

The propagation data in the new frequency bands to be obtained with ATS-F and CTS should make it possible for users of space, such as the education community or the broadcasters, in the last 1970's and early 1980's to employ frequency bands not now readily usable because of technical problems involved in using these bands. These results will also be used by the FCC to establish guidelines and regulations for use of these bands.

(3) Communication Satellite Technology. NASA plans to develop concepts and technology far more advanced than the current and planned state-of-the art in order to meet its own future satellite communications R&D needs and in order to maintain the technological lead in satellite communications. Some examples of the technology currently under consideration for eventual use during the shuttle era are:

(a) The design and development of spaceborne antennas which will produce structured beam contours to fit, for example, within the boundary of a time zone or state, while maintaining a high immunity to interference. This type of antenna will minimize spill-over of information to regions having little or no interest in the data being transmitted.

(b) A multi-level modulation technique that can reduce the communications bandwidth requirement and permit greater efficiency of the frequency spectrum.

(c) Spaceborne and ground subsystem technology to develop the 100 μm (infrared) and 0.5 μm (visible) wavelength regions for satellite communications. These regions have the potential of providing communications capacity many times that presently available.

(d) The design and development of low-cost, low-noise preamplifiers for the 12 to 30 GHz region. This technology should permit greater use of the recently approved [International Telecommunications Union/World Administrative Radio Conference (ITU-WARC)] space communications frequency for communications applications by the user community (education, library, etc.).

(e) The development of highly efficient and reliable 10 to 100 watt transmitters which combine electron beam technology with solid-state components in the 1.5 GHz region. These transmitters should cost much less than conventional travelling wave tubes and, therefore, should be more suitable for satellite applications to ship and aircraft communications and position location.

(4) Communications as a Substitute for Transportation [16]. NASA recently initiated studies to examine the use of telecommunications as a substitute for certain types of business travel. The initial premise is that improvements in the relaying of voice, data, and pictures can replace some of the need for business travel. The first approach entails the use of teleconferencing among a number of distant personnel to conduct business meetings. The Apollo Program used teleconferencing extensively to reduce the travel cost and time spent. Typically, 40 or 50 pages of documents and drawings were distributed to the participating conference rooms by fast facsimile machines prior to the meetings. These documents were projected simultaneously in all conference rooms during the meetings. All of the conference rooms were interconnected by dedicated audio circuits with voice-actuated microphones. Initial indications are that each dollar spent in teleconferencing has saved several dollars in travel funds.

A number of new NASA programs are being analyzed to predict the effects of employing teleconferencing on the management of the program. An experiment will be designed for promising programs and a plan will be developed to provide the participating sites with teleconferencing equipment. Use will be made of existing circuits and terminals and, possible, two-way video links. Ultimately, the video links may use the NASA/Canada CTS to interconnect conference rooms.

(5) Energy Transfer via Microwaves [17]. Another potential application of the technology developed for communication satellites is the use of microwaves to transmit energy. Microwave beams have been used to transmit telecommunications signals for many years. Their use to transmit electric power has been achieved in the laboratory. Recent technological developments have made microwaves potentially more attractive for power transmission than conventional wire conductors because the use of microwaves may have applications in areas where conventional lines are not practical to install — either on the ground or in space.

One application NASA has examined involves the transmission of electrical power from a "mother" space station to nearby satellites. Such a system could have at least two applications:

(a) A nuclear powered "mother" satellite could be removed some distance away from the "daughter" space station to provide power and yet to minimize hazards to and shielding requirements for the instruments on the "daughter" satellite.

(b) "Daughter" satellites requiring tight attitude control may not be able to support large solar arrays and still maintain the necessary attitude control. These satellites could receive their power from "mother" satellites.

4. FLIGHT MISSION SUMMARY

The Government decision that NASA curtail its overall communications satellite R&D, particularly with respect to early commercial applications, has caused NASA likewise to curtail plans for automated satellites with which to develop and demonstrate communications and navigation technology required for future satellite applications. The NASA Mission Model for the 1980-1991 [18] time period contains estimates for C&N missions to be conducted by other federal agencies, domestic and international satellite developers, and foreign governments. DOD-C&N missions are not included. These missions, with write-ups of their objectives and descriptions, are NASA estimates of the planned launches for communications and navigation satellites. Some further discussions with domestic users and the domestic satellite communities are warranted to obtain improved estimates of their future plans.

To support efforts in satellite communications aimed at satisfying broad national needs and the communications needs for NASA's future space missions, NASA's present plan is to employ the Spacelab as the vehicle with which to develop some of the required technology. This will provide the C&N community with a platform for conducting in-space testing of new technology prior to commitment to a future automated spacecraft. Spacelab's ability to return experiments to earth permits an evaluation of space environmental effects on certain telecommunications subsystems.

The decision to utilize the Spacelab's capabilities is partly based on a study conducted by NASA, with industry participation, in mid-1973, of potential communications and navigation technology that could benefit from early flight into space [19]. This study concluded, in part, that Spacelab "provides a practical vehicle for meeting certain of the planned communications and navigation discipline objectives." The study also described 13 candidate experiments for Spacelab and potential future R&D automated satellite missions.

The NASA Mission Model shows that a C&N experiment or experiments will fly on at least one mission per year of Spacelab. If funding support is initiated in FY-76 and beyond for Shuttle Experiment Development, then four early Spacelab missions could have C&N experiments in areas such as radio frequency interference, laser communications, and antenna deployment and applications.

The Spacelab has the advantage of not only providing the platform for the original experiments but also providing the means for reflying experiments to gain more information. In addition, future 30-day Spacelab missions, rather than the initial 7-day missions, will provide principal investigators with more data for statistical analysis.

5. PROGRAM AND MISSION FUNDING

NASA has expended about $64.2 million on the early projects devoted to the demonstration of the feasibility of satellite communications, that is, Echo, Relay, and Syncom. Following these, NASA's communications development efforts were executed as part of the ATS program.

Through FY-73, the ATS-1 through -5 cost approximately $143.7 million, of which about $10 million were for communications-related experiments and $1.7 million were for navigation and traffic control experiments. In addition, NASA has spent about $53.3 million on its supporting research and technology program for communications, navigation, and traffic control. The ATS-F program is currently estimated to cost $180.2 million.

In FY-74, NASA's Office of Applications (OA) received $4.5 million to define potential experiment payloads for Shuttle and Spacelab. C&N received $1.7 million to define eight potential Spacelab experiments. In FY-75, OA requested an additional $4.5 million for Shuttle-Spacelab experiment payloads. C&N is expected to receive an amount close to that of FY-74 to complete the definition of several experiments initiated in FY-74 and to start a number of new ones.

Total costs for Communications Programs from FY-66 through FY-80 are shown in Table V-I and Figure V-1.

6. COST BENEFIT/COST EFFECTIVENESS ACTIVITIES

The Space Transportation System (STS) of the 1980's is expected to enhance substantially the utility, economy, and reliability of communications and navigation satellite placement into synchronous orbit. The STS return trip

TABLE V-1. COMMUNICATIONS PROGRAMS FISCAL OBLIGATIONS

	FY-66	FY-67	FY-68	FY-69	FY-70	FY-71	FY-72	FY-73	FY-74	FY-75	FY-76	FY-77	FY-78	FY-79	FY-80	Total
SRT	3.4	5.1	5.4	5.2	5.0	6.0	7.3	2.0								39.4
TCSS									2.5	1.7	2.7	2.7	2.7	2.7	2.7	17.7
ACR										1.4	2.5	2.5	2.5	2.5	2.5	13.9
RIPP							1.6									1.6
Subtotal	3.4	5.1	5.4	5.2	5.0	6.0	8.9	2.0	2.5	3.1	5.2	5.2	5.2	5.2	5.2	72.6
Spacecraft																
CAS-1				0.1	0.1	0.1	0.1	0.1								0.5
CAS-C								0.3	0.4	0.8	0.3					1.8
ATS 1-5	20.3	14.5	7.0	4.9	4.6		0.1									51.4
ATS-F			12.0	8.4	18.1	17.0	39.6	39.5	12.1							146.7
DWS											1.0					1.0
Subtotal	20.3	14.5	19.0	13.4	22.8	17.1	39.8	39.9	12.5	0.8	1.3					201.4
Experiments																
CAS-C							2.4	1.6	1.7	0.5	0.3					6.5
ATS 1-5	12.8	11.5	9.1	1.0	2.7	2.2	0.9	0.3								40.5
ATS-F			3.5	2.8	11.5	14.1	6.9	9.5	2.1							50.4
AAFE					0.3	1.3	0.4	0.5	0.2	0.5	0.5	0.5	0.5	0.5	0.5	5.7
Exp. Packages											3.8	3.2	0.5			7.5
Exp. Coord. and Ops. Supt.									0.8	6.2	4.2	3.5	3.7	1.5	1.1	21.0
Subtotal	12.8	11.5	12.6	3.8	14.5	17.6	10.6	11.9	4.8	7.2	8.8	7.2	4.7	2.0	1.6	131.6
Ground Operations																
CAS-C							0.1	0.3	0.6	0.8	0.5	0.3	0.2			2.8
ATS 1-5	1.3	2.5	3.7	0.7	0.4	1.1	0.6	1.0								11.3
ATS-F				2.3	3.5	2.5	3.4	2.2	1.8							15.7
Subtotal	1.3	2.5	3.7	3.0	3.9	3.6	4.1	3.5	2.4	0.8	0.5	0.3	0.2			29.8
Manned																
Definition									1.7	1.7	1.0					4.4
Development											0.5	1.0	2.0	3.0	4.5	11.0
Subtotal									1.7	1.7	1.5	1.0	2.0	3.0	4.5	15.4
TOTAL	37.8	33.6	40.7	25.4	46.2	44.3	63.4	57.3	23.9	13.6	17.3	13.7	12.1	10.2	11.3	450.8

Notes:
SRT — Supporting Research and Technology
TCSS — Technical Consultation and Support Services
ACR — Advanced Communications Research
RIPP — Radio Interference and Propagation Program
DWS — Disaster Warning Satellite
CAS — Cooperative Applications Satellite
AAFE — Advanced Applications Flight Experiments

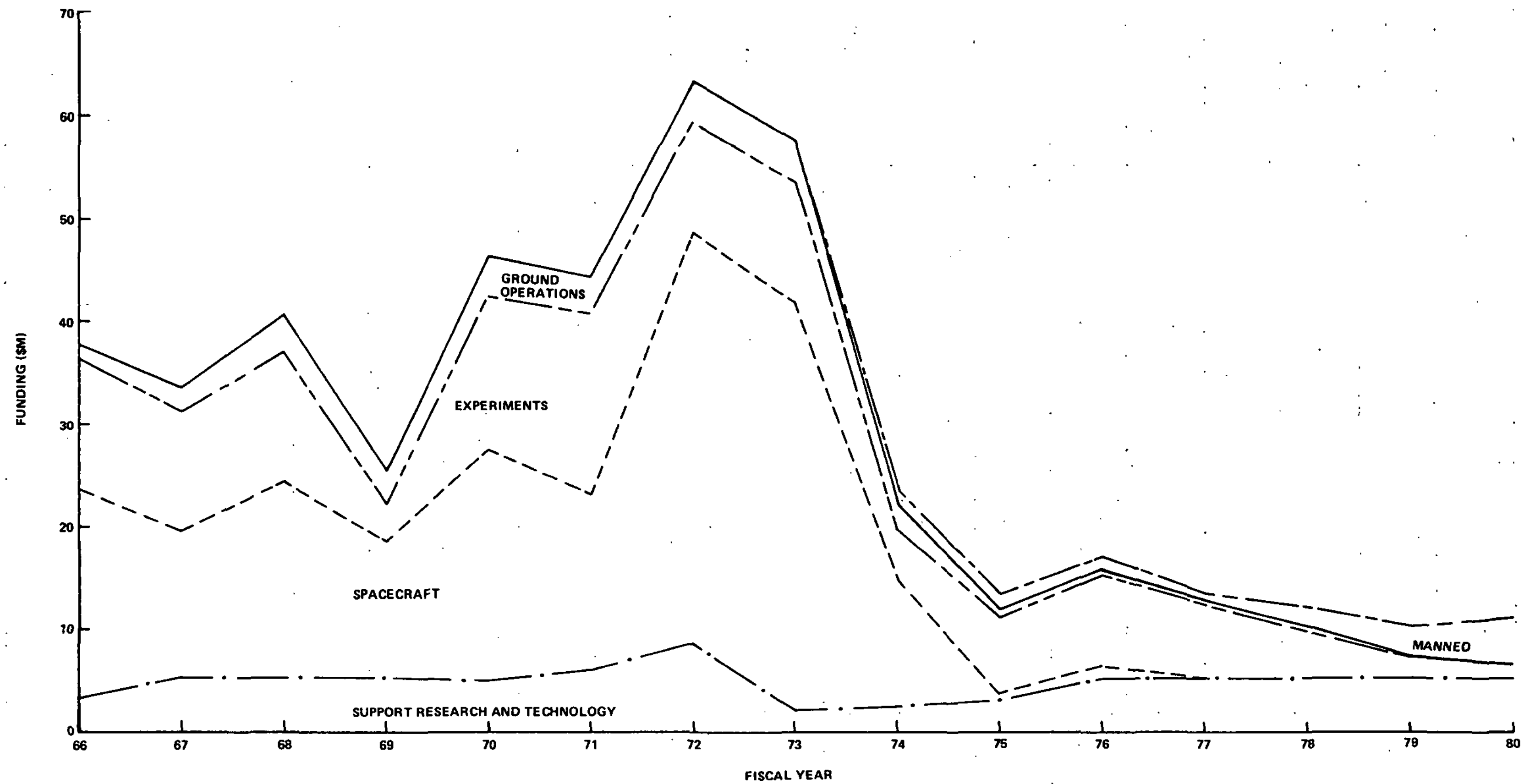

Figure V-1. Communications Programs fiscal obligations.

payload capability, economy of operation, and flexible launch schedule appear to be prime factors in achieving a dependable and economical space system through the utilization of maintainable satellite systems. The expected low operating costs and high reliability of the STS should help to keep the satellite systems costs lower than today's launch vehicle costs.

In a study performed by the Aerospace Corporation [20] of missions expected to be conducted in the 1980-1991 period, specific attention was directed to the potential benefits to communication satellite systems arising from the use of Shuttle/Tug. The study compares two satellite systems — Intelsat and an undefined U.S. domestic satellite system. The major result of the study is summarized below:

> Use of the Shuttle/Tug to launch Intelsats and domestic satellites would provide, as a major benefit, a substantial reduction of the cost per launch due to lower direct costs. Such launches would cost about $12.5 million instead of the $17 or $18 million required per expendable launch. They also would reduce to a negligible amount the currently planned allowances for one failure in four attempts to achieve launch and orbital operation. The assumption of no initial failures to operate on orbit reflects the benefits of Shuttle/Tug payload checkout on orbit.

Shown in Table V-2 are the savings for the Intelsat IV system and a hypothetical domestic satellite system when the Shuttle/Tug is employed to place these spacecraft into the geostationary orbit as compared to present day launch vehicles. These reductions in initial cost are due to the need for few launches, no loss of payload, and reduced cost per launch.

The savings described do not include the other potential benefits of the STS to C&N automated satellites. The repair of in-orbit satellites will be a basic operational mode of the STS. Repair appears appropriate for expensive satellites that are far from reaching their design lifetime. If the new satellite costs more than the cost of repairing the damaged one, it is economically justifiable to repair it rather than to deploy a new one. Indeed, the availability of such in-orbit repair missions will require a new design philosophy for future satellites to take advantage of this feature. COMSAT's experience with their satellite failures has indicated a high accuracy in being able to determine the component and/or subsystem which failed [21]. Extrapolating this experience to the Shuttle time period indicates that adequate information will be available to carry into space the required new part for damaged spacecraft.

TABLE V-2. COST SAVINGS RESULTING FROM THE USE OF THE SHUTTLE/TUG FOR SATELLITE DEPLOYMENT

Satellite	Satellites In Orbit	Reduction in Initial Sat. Costs ($M)	Annual Cost Savings ($M)
Intelsat IV[a]	6	76	23
Domestic Satellite (Domsat)[b]	12	192	61

a. Intelsat IV's operating in orbit cost $37.5 million per operational satellite, including an allowance for failure of one in four launches. Launch costs are $17.0 million each. If the Shuttle/Tug were available for Intelsate IV, the $8.2 million launch failure allowance would not be necessary and the direct launch costs would be reduced roughly $4.5 million. This would represent a total reduction of $12.7 million (or 34 percent) per operational satellite. The reduction in initial cost for six operational Intelsat IV's would be approximately $76 million, or almost $23 million per year.

b. The reduction of initial costs for a Domsat system with eight primary plus four backup satellites by 1981 would be $192.0 million. This figure includes four failed launches (assumption of one failure in four) at $13.5 million for the satellite and $18.0 million for launch costs, or $126.0 million; plus 12 launches at $12.5 million each rather than $18.0 million each, or $66 million. The annual reduction in cost would be $61.0 million.

Other benefits for C&N satellites that the STS will provide are:

(a) In-orbit (low altitude) checkout and partial operation of C&N satellites while in the vicinity of the Shuttle and prior to igniting the upper stage which would place the C&N satellites into final orbit. If the satellite is not functioning in a satisfactory manner, rendezvous will occur and repair will be done while in the Shuttle bay or the satellite will be returned to earth for repair.

(b) Lower cost for the satellite development because weight and volume of subsystems are not critical problems.

(c) Reduced costs for development, test, and manufacture resulting from relaxation of weight and volume limits and documentation requirements.

(d) Increased launch reliability and decreased interface problems, resulting from continuity of experience with a standardized launch vehicle and launch operations.

Finally, COMSAT performed an assessment of the potential benefits of in-orbit servicing of synchronous orbit satellites using the STS [21]. The study concluded that:

(a) The present plans for servicing of unmanned communication satellites at geostationary orbit are attractive.

(b) The major benefit of servicing communication satellites will be added reliability and availability that cannot be achieved by present day satellites.

(c) Bringing a communication satellite back to the ground for servicing is less attractive than in-orbit servicing, at least for a chemical propulsion tug.

(d) The approach of designing a communication satellite to make the in-orbit servicing easier is more attractive than servicing unmodified satellites.

7. INSTITUTIONAL ARRANGEMENTS

When the phase-down of NASA's communications R&D was announced, several executive and legislative agencies that traditionally relied on NASA to provide technical consultation and support for their needs in satellite communications expressed concern, since NASA has a statutory obligation to provide such services. Under the Communications Satellite Act, NASA is to advise the FCC on the technical characteristics of various communications satellite systems and designs. NASA recently performed studies for the FCC on the technical feasibility of eight industry applications for domestic satellite systems. NASA conducts design and flight readiness reviews for the FCC on the INTELSAT satellites prior to launch and provides technical advice on plans and proposals put forward by COMSAT as the manager of INTELSAT. This responsibility has been extended to domestic communications satellite companies by FCC request. All services supplied to COMSAT and other prospective domestic satellite organizations are on a reimbursable basis.

NASA advises the Department of State on the suitability of transferring U.S. communication technology to foreign countries.

The Office of Telecommunications Policy on January 13, 1974, notified various federal executive departments and agencies that NASA's technical support capabilities in communication satellites will be available to other government agencies on a reimbursable basis. NASA is ready to assist these agencies, to the extent that its resources permit, with its personnel and systems experience to meet their communications technology needs for the future.

A formal agreement exists between NASA and the Department of Commerce's Maritime Administration to utilize satellite technology in commercial maritime shipping systems in the areas of ship safety, navigation, communications, and general operations. During the period since the agreement came into force (November 9, 1971), NASA has worked with them in conducting ship-satellite telecommunications tests with the ATS-5 and in planning and implementing the ATS-F maritime voice, data communications, and position location experiments.

8. REFERENCES

1. National Aeronautics and Space Act of 1958, As Amended through Oct. 3, 1964.

2. Communications Satellite Act of 1962.

3. Space Task Group Report to the President, the Post-Apollo Space Program: Directions for the Future, Sept. 1969.

4. A Report for the Space Task Group: America's Next Decade in Space, Sept. 1969.

5. NAS-Useful Applications of Earth-Oriented Satellites — Report of the Central Review Committee, 1969.

6. NAS-Useful Applications of Earth-Oriented Satellites — Summary of Panel Reports.

7. The ATS-F and -G Data Book, Sept. 1972.

8. The HEW/NASA HET Experiment Summary Description, Nov. 1973.

9. Satellite Instructional Television Experiment (SITE), Jan. 1974.

10. Integrated Test Plan for ATS-F L-Band Experiment, Sept. 1973.

11. A High-Power Communications Technology Satellite for the 12 and 14 GHz, Apr. 1972. Presented at AIAA 4th COMSAT Systems Conference.

12. Communications Experiment Guide for CTS, Sept. 28, 1972.

13. First and Second U.S. User Meetings — CTS, Oct. 30-31, 1973; Jan. 23-24, 1974.

14. ORI Final Report, Study of Data Collection Platform Concepts, Apr. 1973.

15. NAS-Useful Applications of Earth-Oriented Satellites, Report 7, Points-to-Point Communications.

16. NASA Experience in Telecommunications as a Substitute for Transportation, Fordyce/NASA HQ, Dec. 1973.

17. Microwave Energy Transmission — A Proposed 5-Year Development Plan, Fordyce/NASA HQ, Aug. 1973.

18. The 1973 NASA Payload Model — Space Opportunities 1973-1991, Oct. 1973.

19. Final Report of the Space Shuttle Payload Planning Working Group, Volume 6 — Communications and Navigation, May 1973.

20. Aerospace Corp.: Final Report Space Shuttle Mission and Payload Capture Analysis, Volume 11. June 1973.

21. COMSAT: Assessment of On-orbit Servicing of Synchronous Orbit Spacecraft. Dec. 1973.

CHAPTER VI. THE SPACE PROCESSING PROGRAM

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

CHAPTER VI. THE SPACE PROCESSING PROGRAM

1. HISTORY

a. Origins. The NASA space processing program originated in the late 1960's from a set of ideas motivated by engineering research on topics such as propellant management, fire control, and the assembly of structures in space. All of this work involved the behavior of weightless materials undergoing chemical and physical changes, and results from tests performed in drop towers and ballistic trajectory aircraft flights provided many illustrations of how much this behavior could differ from what was commonly observed on the ground. For example, it was found that unrestrained liquid masses would form large free-flying globules[1], that vapor bubbles could grow virtually without limit in boiling liquids, and that flames quickly became blanketed with their own combustion products. Moreover, in addition to such easily observed phenomena, it was realized that other, more subtle effects should occur because the driving forces for normal convection and sedimentation or settling processes would be removed.

Initially the specific effects of weightlessness were treated almost purely as problems that made it difficult to get predictable results in the engineering of spacecraft systems. As studies of them progressed, however, these effects proved to be so interesting in themselves that ideas for exploiting them were soon suggested by several sources. From the beginning, one of the main thrusts of such thinking was toward the invention of novel processes to manufacture products in space for use on earth, and interest in the idea of space manufacturing was especially high among materials engineers.

b. Initiation of NASA Space Processing Program. The first concrete steps toward a NASA space processing program were taken by the George C. Marshall Space Flight Center (MSFC) beginning in 1966 or 1967 when MSFC personnel started a series of visits to manufacturing companies to explore their interests in space applications. These contacts culminated in two symposia held in 1968 [1] and 1969 [2], where presentations on space processing concepts were made to audiences that included many representatives from commercial industry.

The upshot of this activity was to show that space processing held enough promise to arouse interest and even enthusiasm among scientists and engineers, but its applications were too far in the future to be of practical

---

1. A rediscovery of the invention of bullet-forming drop towers.

concern to management in any but the aerospace and R&D industries. Commercial interest has increased somewhat in recent years, but at the time it was clear that NASA would have to take the initiative in development for the foreseeable future. Accordingly, in 1969 the Agency initiated its first formal space processing activities under the joint sponsorship of the Office of Manned Space Flight (OMSF) and the Office of Advanced Research and Technology (OART) [since renamed the Office of Aeronautics and Space Technology (OAST)]. The formal title of the OMSF program was Materials Science and Manufacturing in Space (MS/MS).

The first activity initiated was the development of three space processing experiments designed to test and, if possible, demonstrate process concepts that were then current. The new experiments were consolidated with two older welding and brazing experiments as a set of tasks to be performed in the M512 Materials Processing Facility on Skylab.[2] Somewhat later in the year a small group of exploratory studies of more advanced concepts was also initiated. Thus, a program of flight experiments and a Supporting Research and Technology (SRT) program were started simultaneously in space processing, and the two have continued at roughly equal levels of effort throughout the program's history.

The ensuing 2 years of relatively low-level activity in the SRT program disproved a few naive ideas that existed at the program's outset but also produced a surprisingly large input of new ideas. In fact, it quickly became evident that space processing was a considerably more fertile field than its early proponents had supposed and that its potential applications cut across a wide range of materials-related areas, including metallurgy, electronic materials, biological preparations, ceramics and glass, and the physics and chemistry of fluids. As a result, space processing has received continually increasing emphasis and funding in NASA since FY-71.

c. Apollo Demonstrations. The SRT program's early results also made it clear that a serious effort would have to be made to increase the scope of the flight experiment program in accordance with the increased scope of NASA's interests. The first step in this direction was taken in mid-1970, when an opportunity was identified to perform a series of simple experiments

2. The new experiments were designated M553, Sphere Forming; M554, Composite Casting; and M555, Gallium Arsenide Crystal Growth. At this time the welding experiment was redesignated as M551, Metals Melting, and the brazing experiment as M552, Exothermic Brazing.

on the transearth coast phase of the Apollo 14 lunar mission. In the last 4 months of the year, three demonstrations were developed and delivered; they were performed in flight in January 1971 [3-5].[3] Results revealed a few unexpected physical effects and also provided engineering experience which has proved invaluable in the design and development of more recent experiments. The lines of research opened by the Apollo 14 demonstrations were subsequently continued by a more ambitious electrophoresis demonstration on the Apollo 16 mission [6] and a heat flow and convection demonstration on Apollo 17 [7].

d. Skylab Experiment Program. Although the Apollo demonstrations fell short of several of their more ambitious objectives, they showed that worthwhile results could be obtained in space processing by relatively simple and inexpensive experiments. In addition, by mid-1971 results from the SRT program and the Skylab experiment projects indicated that a substantial expansion of the Skylab space processing program would be feasible within the time remaining before the first mission. Accordingly, definition studies of potential, new apparatus were initiated by OMSF late in 1971, and two Announcements of Flight Opportunity for use of this equipment were issued in January 1972. Three definition projects were carried out [8] and in June the Manned Space Flight Experiments Board (MSFEB) approved the most promising equipment system for flight. This system was designated the M518 Multipurpose Furnace System; the equipment and samples for 11 experiments to use it were delivered for installation in the spacecraft at the end of 1972. The total Skylab space processing experiment program that resulted is summarized in Table VI-1.

All of the experiments[4] were completed as originally planned on the first two missions except for M555, whose stowage space was preempted on both missions by repair kits. Seven of the furnace experiments were repeated using backup sets of samples on the last mission, and a number of small ad hoc "science demonstrations" were also prepared in response to crew requests for supplementary activities and performed on the last two missions. Postflight evaluation reports are available on all of the Skylab experiments [9] so only the highlights of their results will be summarized here.

3. The three demonstrations were titled Heat Flow and Convection [3], Electrophoretic Separation [4], and Composite Casting [5]. The term "demonstration" was adopted to distinguish these minor experiments from the formal experiment program whose objectives were criteria of mission success.

4. When the Multipurpose Furnace was developed, experiment M554 from the original set of five was redesigned to use it and redesignated as experiment M566.

TABLE VI-1. SKYLAB SPACE PROCESSING EXPERIMENTS

M512 Materials Processing Facility			
M551:	Metals Melting Experiment Mr. R.M. Poorman, MSFC Astronautics Lab.	M553:	Sphere Forming Experiment Mr. E.A. Hasemeyer, MSFC Process Eng. Lab.
M552:	Exothermic Brazing Experiment Mr. J.R. Williams, MSFC Process Eng. Lab.	M555:	Gallium Arsenide Crystal Growth Experiment Dr. R.G. Seidensticker, Westinghouse Res. Lab.
M518 Multipurpose Furnace System			
M556:	Vapor Growth of II-VI Compounds Prof. H. Wiedemeier, Rensselaer Poly. Inst.	M561:	Whisker-Reinforced Composites Dr. T. Kawada, Nat. Inst. for Metals Res., Japan
M557:	Immiscible Alloy Compositions Mr. J.L. Reger, TRW Systems	M562:	Indium Antimonide Crystals Prof. H.C. Gatos, MIT
M558:	Radioactive Tracer Diffusion Dr. A.O. Ukanwa, MSFC Space Sciences Lab.	M563:	Mixed III-V Crystal Growth Prof. W.R. Wilcox, U. of Southern Calif.
M559:	Microsegration in Germanium Dr. F.A. Padovani, Texas Instruments	M564:	Alkali Halide Eutectics Prof. A.S. Yue, U. of Calif, Los Angeles
M560:	Growth of Spherical Crystals Dr. H.U. Walter, University of Alabama	M565:	Silver Grids Melted in Space Prof. A. Deruytherre, Katholieke Univ. Leuven, Belgium
M566:	Copper-Aluminum Eutectic Mr. E.A. Hasemeyer, MSFC Process Eng. Lab.		

e. Skylab Experiment Results. Possibly the most significant Skylab finding for the future of space processing was that at least four of the 14 experiments, or about 30 percent of the total program, produced unexpected results with implications beyond their planned objectives. This was a surprisingly high degree of technical productivity for a small group of relatively simple experiments, and it seems to indicate that important discoveries in materials science and technology may come from the more capable payloads planned for future flight programs.

All of the Skylab experiments involved solidification processes of various sorts, and all of the cases that produced unexpected results involved solidification of materials that were not supported or at least not effectively constrained by containers.

Experiment M562 was designed to demonstrate that doped semiconductor crystals produced by unidirectional solidification of weightless melts in crucibles would have extremely uniform impurity concentrations because there would be no thermal convection in the melt to produce growth fluctuations. That hypothesis was verified in the indium antimonide crystals produced by this experiment and was substantiated by the results of experiment M559, in which similar procedures were followed with germanium samples. However, indium antimonide contracts upon melting, and some of the samples pulled away from the walls of their containers to form columns of liquid with essentially unsupported lateral surfaces. Analysis of the sample surface showed that liquid motions driven by temperature-dependent variations of surface tension (known as the Marangoni effect) had occurred, but the internal structures of the crystals indicated that the motions were confined to very shallow surface layers and produced no bulk effects. Since the Marangoni effect is the principal known driving force, other than gravity, for convection, this finding was favorable for future work on convectionless crystal growth. In addition, the internal structures near the sample surfaces contained some suggestive indications regarding the origins of growth twins (internal boundaries where one or more elements of crystal symmetry are abruptly reversed) at curved portions of the solid-liquid interface. If the interpretation of these features is confirmed by further analysis, it should open the way to control of this class of crystal imperfections.

Experiment M560 was intentionally designed to study crystal growth in unsupported melts. The free ends of cantilevered single crystal rods of indium antimonide were melted to form pendant drops of liquid and then heat was extracted through the unmelted solid portions, which acted as seed crystals for the resulting solidification process. The crystals produced in this way

were more perfect than the original rods as the Principal Investigator had expected, but the density of crystal defects decreased monotonically with increasing distance from the original solid-liquid interface in an unexpected way. In this case the defects were dislocations (a particularly intractable type of imperfection in which part of the crystal is slightly displaced with respect to the rest), and a full interpretation of their systematic density variation may lead to efficient techniques for eliminating them entirely. It wal also found that the shapes of the crystals entirely failed to conform to those of the liquid drops; in fact, their shapes were so nearly cylindrical that at first it was believed that the molten material had adhered to the ends of the cavities containing the cantilevered rods. Moreover, about 30 percent of the surface area of each crystal was covered with growth facets that proved to be optically flat (i.e., flat to within about ±100 Å) although the curved parts of the surface beside them showed clear evidence of mechanical vibrations in the melt. This demonstration of how effective the forces intrinsic to solidification can be in shaping crystals appears to offer a basis for fresh space-based approaches to the problem of growing semiconductor crystals directly as thin, flat sheets, which has so far resisted all development efforts made on the ground.

In experiment M553 the samples were beads of nickel and three of its alloys with tin, copper, and silver, which were melted in an electron beam and then allowed to freeze by free cooling. A few samples froze while drifting without restraint in the vacuum chamber of the electron beam apparatus and the others froze while resting on solid supports. In each case all or most of the molten sample surface was unconstrained, so motions of material during solidification were entirely due to forces generated by the process itself. The result was a uniquely detailed and informative record of the stages of polycrystalline solidification, including such features of interest as undisturbed terminal phases in contact with the solid from which they had segregated and what are believed to be the first direct observations ever made of dendrites with growth spirals visible at crystallographically determined locations on their tips. Evidence was also found for an effect, never before observed, in which the changing pressure and composition of the residual liquid combined to produce substantial increases in the rate of evaporation as the temperature fell. These and other effects seen in the M553 samples have shown that space techniques can produce results in physical metallurgy that can be obtained in no other way, and the experiment has opened lines of research that are likely to remain active at least through the 1980's.

Finally, experiment M556 was designed to investigate production of crystals of the semiconducting compounds GeTe and GeSe by chemical vapor transport with iodine in a temperature gradient. It was expected that

weightlessness would improve the perfection of the crystals obtained at high vapor pressures because vapor convection would be suppressed, and indeed this proved to be the case.

Crystal platelets of regular rectangular habit were produced under conditions that produce only polycrystalline dendritic material on earth. Most of the platelets were in the 2 to 5 mm size range predicted by theory and previous experimental experience, but at the highest pressure employed one crystal of GeSe was produced that was 18 mm long. This is believed to be the largest single crystal of GeSe ever grown, and the reasons for its occurrence are not yet completely understood. However, there is some evidence that the rate of material transport may have been anomalously high, and it has been suggested that the large crystal could have grown from a nucleus that formed spontaneously in the free vapor rather than on the wall of the container. On the practical level, the growth of such a large crystal indicates that vapor growth processes in space should be capable of producing crystals of many compound semiconductors in sizes appropriate for electronic device applications.

Within their limited scope the small "science demonstrations" performed on Skylab were similarly productive [10] and two were of special interest. One was a simulation of floating zone refining in which it was shown that a cylinder of water with a free lateral surface could be suspended in contact with end pieces of material that the water would wet. Internal flow effects were observed in the liquid under conditions analogous to those existing in zone refining, and it was demonstrated that at high rotation rates the liquid zone made the same transitions to higher rotational modes as are well known for flexible solid shafts. A byproduct of this demonstration was that when motion pictures of it were shown at a European space processing symposium, Mr. John G. Watt of the Scottish National Blood Transfusion Service pointed out that it demonstrated the feasibility of performing electrophoretic separations in containerless media.

The other especially interesting demonstration was a quickly improvised test of isotachophoresis, an advanced electrophoretic separation method that was being considered for inclusion in the NASA electrophoresis experiment for for the Apollo-Soyuz Test Project (ASTP) mission. The demonstration accomplished the first isotachophoretic transport of cells ever performed in an unstabilized liquid medium and confirmed expectations that this technique can produce sharply defined fractions of sample materials to which it may be applied in the future.

f. <u>Supporting Research and Technology Program</u>. The space processing program's SRT component has evolved parallel with its experiment activities, and in fact the SRT effort has provided much of the impetus and technical basis for the experiments undertaken so far. For example, preliminary design and development for the Skylab multipurpose furnace and for a second furnace and electrophoresis apparatus for the ASTP mission were conducted as SRT projects. All work except construction of flight hardware was also accomplished in this way for the Apollo 14 demonstrations. Moreover, 7 of the 14 completed Skylab experiments and 5 of the 10 experiments approved for ASTP originated from SRT projects, as did all of the ideas for the Apollo demonstrations and all but one of those for the Skylab demonstrations. Thus the interplay between the SRT and flight experiment programs has been close; in the future it will be augmented by projects based on the results of previous experiments, as well as investigations of new experiment concepts.

As its name implies, the SRT program provides for exploratory research and technology development in space processing, and as the program's areas of interest have expanded the SRT program has expanded and diversified as well. At present there at 66 active SRT projects, most of which are of the size appropriate to provide for effort by a single full-time professional scientist assisted by the usual range of supportive services. Of this total, 50 are being performed in house or through contracts by MSFC, and the rest are distributed as follows: Jet Propulsion Laboratory (JPL), 5 projects; the National Bureau of Standards (NBS), 5 projects; Langley Research Center (LaRC), 3 projects; Johnson Space Center (JSC), 2 projects; and Ames Research Center (ARC), 1 project. The content of the program's work is summarized below.

Metallurgical projects active at MSFC include studies of the general effects of weightlessness in alloy solidification, and applications of weightlessness in preparing composite materials, controlled eutectic structures, and novel structures in monotectic alloys. Where possible and appropriate, this work has included free-fall experiments in the MSFC drop tower and in ballistic trajectory aircraft flights. Work is also being done on applications of supercooling effects, and one project contracted by MSFC is seeking to exploit improvements in levitation melting technology on the ground to demonstrate the feasibility of a space-based method for making ductile tungsten of greatly improved quality. The other active centers of metallurgical effort are LaRC and NBS, both of which have interests in ultrapurification of refractory materials using the ultrahigh vacuum techniques which LaRC is developing.

Aside from one small MSFC study of semiconductor device processing, all of the program's work on electronic materials is concerned with crystal growth. Work performed or sponsored by MSFC includes semiconductor

crystal growth by vapor transport and from melts by the Bridgman, Czochralski, and floating zone methods, as well as growth of insulating crystals from solution in water and high temperature melts. NBS has a single continuing project on growth of insulating crystals by vapor methods.

The only biological application of space processing that has been systematically investigated so far is electrophoretic separation and purification of biological materials. This work is centered at MSFC and has come to be concentrated on preparation of pure fractions of human cells; the preparation methods under development include zone electrophoresis in static and flowing liquid media and isotachophoresis in static media. An independent assessment of these applications has just been completed by the American Institute of Biological Sciences (AIBS) under the auspices of the NASA Life Sciences Office [11], and consideration of prospects for non-electrophoretic biological applications has recently begun at JSC.

Work on glass and ceramics is divided between MSFC and JPL. The projects sponsored by MSFC are principally concerned with prospects for making new kinds of glass by containerless processing methods, while the JPL effort is on novel ceramic applications based on weightlessness.

Most of the program's work on physical processes in fluids has been devoted to assessment of the extent to which buoyant convection is suppressed at the acceleration levels found in real spacecraft and the potential importance of convective processes driven by nonbuoyant forces. Projects have included a series of studies by MSFC and an NBS project on the mathematical theory of the Marangoni effect.

The only currently active project in chemistry is a small scale study at ARC on the feasibility of using weightlessness to increase the structural regularity of long-chain molecules produced by catalytic polymerization. However, consultants working with MSFC have begun to point out potentials for nonbiological chemical separations by electrophoretic methods.

The research and study effort outlined above is supported by a set of five consulting committees maintained under a contract between MSFC and the Universities Space Research Association (USRA). Committees are active in the fields of solidification of metals and semiconductors; electrophoretic, chemical and biochemical separation processes; preparation of glasses; convection and heat flow; and containerless processing systems. Each has recently prepared an overview report on space processing prospects in its particular field [12].

Efforts in technology development have naturally tended to run behind the exploratory research effort during the program's early years, since a certain degree of process definition is necessary before technology needs can be identified. However, a fairly large and diversified advanced technology program has developed in addition to the work mentioned above on flight experiments.

For example, although the MSFC electrophoresis technology effort has been closely intertwined with studies of materials for future applications and with engineering of flight experiments, it has included a fairly strong advanced technology component. The accomplishments of this effort include improvements in apparatus design for continuous flow electrophoresis, development of surface coatings that suppress electrically driven convective effects, and the invention of an effective method for injecting and collecting sample materials in static liquid media. Current advanced technology work includes extensions of these results and also development of methods to detect and make concentration measurements on separated sample materials.

The space processing program's longest standing technology activity has been in methods for manipulating and controlling the positions of samples of material levitated in spacecraft for containerless processing. Electromagnetic methods for simultaneous heating and position control of conducting materials have been under study and development under MSFC sponsorship since 1969; by now technology is available to build flight equipment in any of several configurations when required. Projects on acoustic methods for materials that can or must be handled in gaseous media were initiated by both MSFC and JPL, and the capabilities established so far include three-axis control of positions and rotation rates and levitation of small objects in ambient temperatures up to 1000°C in laboratories on the ground.

Work on the technology of electric furnaces for space use has been an MSFC effort, and as indicated above it has been closely connected with efforts to define or prove the feasibility of successive items of flight experiment apparatus. The latest projects along these lines have developed prototypes of apparatus for sounding-rocket experiments and modified the Skylab multipurpose furnace to reduce its power consumption and cooling time by 30 and 50 percent, respectively, for the ASTP mission. Advanced work is also being done on a lightweight system for use in the 1000 to 2000° C temperature range.

Finally, LaRC is conducting coordinated work under contract and in house to develop facilities to take advantage of the spacecraft wake effect to produce large volumes of ultrahigh vacuum behind an appropriately designed

shield deployed in orbit. Calculations performed so far indicate that vacua of the order of 10^{-13} to 10^{-15} Torr should be achievable with high effective pumping speeds, and that the principal engineering problem will be to maintain adequately clean surfaces on equipment exposed to the vacuum space.

g. Payload Planning Activities. The space processing program has been called upon to provide payload information for two large flight programs besides Apollo, Skylab, and ASTP. The first of these is the Space Station program, for which planning activities were conducted in 1969-1971, and the second is the current Space Transportation System (STS) program, which includes the Space Shuttle and Spacelab. In both cases payload planning had to address the problem of specifying experiment programs to guide the design of very large manned spacecraft that would operate for periods of years, although in much different modes. Similar methods were used for both, and concepts of space processing payloads for post-Saturn/Apollo flight systems underwent a more or less continuous evolution.

The Space Station is envisioned as a large vehicle with a crew of 6 to 12 men which could be operated continuously in orbit for at least 5 years, and representative payload specifications were needed from the beginning as direct data for design of some spacecraft systems and for operational planning that sensitively affected other systems. All NASA science, applications, and technology programs responded to this need in the fall of 1970 by working out concepts for representative experiments in their disciplines and identifying specifications for conceptual designs of apparatus that would meet the experiments' requirements. The results were published in January 1971 [13].

When the question of specifying a 5-year space processing experiment program was seriously considered, it was realized that the only realistic course was to describe operations that would be typical of general research in the program's areas of interest, because it was expected that the program would comprise highly diversified research and development involving many different investigators. For the same reason the design philosophy adopted for the payload equipment was to provide general purpose laboratory facilities to serve all investigators, with apparatus that could be configured as needed for each type of experiment using little or no specialized fixtures. Specifications were derived for an inventory of 70 major items of equipment to support 13 different classes of experiments [14].

From the standpoint of payloads, the Space Shuttle resembled the Space Station in that it provided for a continuously operating, manned experiment program. As regards space processing, the chief difference between the two was

that the Shuttle had smaller electrical power resources and an operating mode more compatible with the discipline's needs to maintain a large inventory of equipment and recover processed materials frequently. It was, therefore, possible to meet Shuttle payload planning needs up to mid-1972 with resources available in house, using equipment specifications derived from conceptual designs scaled down from those used for the Space Station.

Since space processing payloads were envisioned as modular and extremely flexible in configuration, it was clear from the beginning that the Shuttle sortie missions would provide many opportunities for sharing resources with other payloads, and, in fact, it seemed probable that some sort of space processing equipment could be carried on every mission. The program has, therefore, continued to carry its primary equipment specifications in the form of a large matrix of relatively small equipment items that can be assembled into literally hundreds of different payloads for specific objectives and mission resources. Illustrative payloads were compiled from the matrix of specifications to identify Shuttle/Spacelab vehicle requirements and to support accommodation studies, but for operational planning, the payloads will be configured individually.

Contracted payload engineering effort was initiated in mid-1972 in parallel with the work of the NASA Space Shuttle Payload Planning Working Groups, which was formed to establish guidelines on how science, technology, and applications programs would use the Shuttle/Spacelab system. In the fall of 1972 both groups formulated revised experiment requirements reflecting the substantial increase in the scope of space processing since the Space Station requirements were compiled. The contracted study then proceeded to derive functional apparatus requirements and construct Shuttle-compatible layouts and specifications based on conceptual designs for an expanded inventory of equipment [15]. In the course of the conceptual design work the contractor surveyed available technology in the terrestrial laboratory apparatus industry and concluded that most of the required equipment could be built on special order by commerical suppliers, but that the equipment designed for use on earth would not be practical for the Space Shuttle without extensive modifications.

On the other hand, the Working Group considered general discipline objectives, program plans, and policies for space processing in the 1980's [16]. Two major insights resulted from this work: (1) It was realized that even minimal coverage of the 50 research and development topics identified by the Working Group would call for hundreds of space experiments per year and of the order of a hundred individual investigators. These estimates were much larger than those previously made, and they led to increased emphasis on

payload sharing as a way of obtaining adequate numbers and frequencies of flight opportunities. (2) As a corollary to the first conclusion, it was recognized that extensive automation would be necessary to make effective use of payload sharing opportunities and attain the productivity levels implied by foreseeable experiment requirements.

In the year since the publication of the Working Group report, requirements based on its conclusions have been included in the revised NASA Mission Model [17] and in the NASA input data provided to the Shuttle and Spacelab development projects through the Shuttle System Payload Data (SSPD) study [18, 19] and the Joint User Requirements Group (JURG). Concurrent contractual efforts have been concerned with payload-vehicle interfaces and particularly with the engineering of auxiliary power sources and radiators to meet the large energy requirements foreseen for space processing [20]. More recently a separate study of automation methods for space processing payloads has also been initiated [21].

2. GOALS AND OBJECTIVES

The overall goals of the NASA space processing program are to develop socially and economically beneficial applications of space flight for the preparation or processing of materials for use on earth and to facilitate the operational delivery of such benefits when they become feasible. It is expected that the delivering organizations will be found in private industry in cases that have commercial application and in government for activities carried on for public purposes.

The first examples of applications satisfying the program's goals are expected to be research and development activities in which space techniques will be employed to obtain useful results sooner and/or less expensively than would be possible on the ground. Sponsors of this type of work will be motivated by objectives ranging from engineering data acquisition to the invention of new products, and such activities may develop rather early. If space proves to be a cost-effective setting for industrial research, they should continue indefinitely.

It is also believed that space flight provides a basis for techniques that can be used to unique advantage in specialized manufacturing processes and some of the Skylab experiment results given in the preceding section lend credence to that view. New techniques will be invented and further results will accumulate at accelerated rates as increasing numbers of investigators pursue their interests. It, therefore, seems reasonable to suppose that a sufficient level of materials research and development activity in space may result in the invention of economically feasible space products, and, if so, that privately funded operations will eventually be instituted to manufacture them.

NASA's space processing goals thus imply objectives in applied research as well as manufacturing, but they also imply that the ultimate criterion of success for the space processing program is whether or not it can induce private and public organizations to adopt and pursue such objectives. Accordingly, although the NASA program must temporarily take the lead in space processing applications, it must also interact with the potential delivering organizations for such applications so as to facilitate their profitable entry into space.

NASA's functions in this interaction are envisioned as follows:

a. To identify promising space processing areas.

b. To interface with industrial and public organizations in defining their interests.

c. To develop the space technology needed for practical space processing applications.

d. To provide users with easy access to low-cost space transportation.

On the other hand, its objectives in performing these functions are to elicit the following complementary actions by industry and other government organizations:

a. To identify beneficial commercial and public space processing applications.

b. To exploit space as a new resource for applied research and development.

c. When appropriate, to undertake space manufacturing operations.

3. IMPLEMENTATION

a. Summary Program Plan. The historical section of this report has outlined how the space processing program evolved through exploratory projects that were conducted on the ground and supplemented when possible by space experiments on manned missions. This exploratory work has now fairly well characterized the general shape of the technical areas of interest for space processing. Although further ground research will produce a regular flow of new ideas and the ASTP mission will add to the fund of space data, it seems unlikely that either will radically change the picture that is already in

view. On the other hand, the Skylab experiments have demonstrated how rich in unexpected information space experiments in materials can be, and on this basis one may expect space processing concepts to enter a new phase of rapid development when the Space Shuttle and Spacelab make it possible to perform research and development in space as systematically as on the ground.

Since it seems that the Shuttle flight program will provide for the next burst of progress in space processing, the space processing program's major assignment for the remainder of the 1970's must be to prepare for full utilization of the Shuttle/Spacelab system. One obvious program requirement will be to develop payload equipment on a scale that can support a systematic, continuing experiment program much larger than the Skylab and ASTP programs. In addition, however, it will be necessary to develop a user group in the scientific and industrial community that is large enough and well enough prepared to make adequate use of the Shuttle and Spacelab. In some respects the latter requirement will be the harder one to meet because it cannot be satisfied by straightforward engineering effort. The space processing program's activities in the 1970's will seek to meet both of these needs.

In the areas embraced by the SRT program the search for new ideas will be continued at an appropriate level, but the main emphasis will be placed on suporting preparations for the Shuttle/Spacelab program. Apparatus technology projects will be oriented toward advanced development for critical Shuttle payload components, and the thrust of ground research and analysis of flight experiment data will be toward basic processes that will be represented in the Shuttle experiment program.

From 1975 through 1980, the space processing program will also conduct a series of sounding rocket experiment flights to develop user interest, build up a cadre of experienced experimenters, and augment its fund of space experiment data. Available sounding rockets have large enough payloads to support multiple experiments and long enough flight times to acquire useful data in many areas of interest. Since the rocket program will provide repetitive flight opportunities over a period of years, it is expected to be of value to both NASA and the user community as a small-scale rehearsal for the Shuttle/Spacelab program.

Phased Shuttle payload development will be conducted through the 1970's, with user involvement obtained first through an Announcement of Planning Opportunity and subsequently through Announcements of Flight Opportunity. The equipment to be developed before the first Shuttle flight will be designed to provide for early applied research activities, and new equipment will be added

continually during the Shuttle program as new requirements develop. The payload equipment to be provided for research and development is intended to be modular and general in application, so that it can serve multiple experimenters and can be configured as required for all types of missions.

In the early years of Shuttle operations the space processing experiment program is expected to comprise quite diversified applied research activities by materials scientists and engineers, most of who will be new to space work and will, therefore, probably tend to pursue rather general and preliminary objectives. It is believed that this kind of activity can be supported most efficiently by frequent flights of small payloads that share the Shuttle with equipment from other programs, rather than by widely spaced flights dedicated to space processing. In later years, however, maturing development programs and more ambitious experiments will probably impose requirements that only dedicated missions can support.

b. ASTP Experiment Program. The experiment program planned for Apollo-Soyuz Test Project mission in 1975 is essentially a continuation of the activities initiated by the Skylab Program. The ASTP experiment program is outlined in Table VI-2; it consists of seven experiments to be performed in the MA-010 Multipurpose Furnace (a modified and upgraded version of the M518 furnace carried on Skylab), two electrophoresis experiments, and a small experiment on crystal growth in solutions, funded on a cooperative basis by NASA and the Rockwell International Corporation.

Among the furnace experiments, MA-060, MA-085, and MA-131 are to be conducted respectively by the investigators who were responsible for the Skylab M560, M556, and M564 experiments since they represent continuations of the Skylab research projects. Experiment MA-041 is designed for further study of the Marangoni effect discussed previously in connection with experiment M560. Experiments MA-044 and MA-070 will pursue essentially new objectives, i.e., forming homogeneous intermetallic compounds and controlled metallurgical structures, respectively. MA-150 will be an exploratory experiment sponsored by the Soviet Academy of Sciences.

The two electrophoresis experiments will use separate apparatus, but both will seek to separate certain classes of human cells into groups that have different characteristics that are important for medical research and applications. Electrophoresis is an electrical separation technique that works on molecules or particles suspended in aqueous solutions; the fundamentals of the process are outlined in the following section.

TABLE IV-2. ASTP EXPERIMENTS

	Electrophoresis Experiments
MA-014:	Electrophoresis-EPE Dr. K. Hannig, Max Planck Inst.
MA-011:	Electrophoresis Technology Dr. R.S. Snyder, MSFC Astronautics Lab. Dr. P.E. Bigazzi, State U. of New York Mr. G.A. Barlow, Abbott Laboratories Dr. M. Bier, Veterans Administration
	MA-010 Multipurpose Furnace System
MA-041:	Surface Tension Induced Convection Dr. R.E. Reed, Oak Ridge Nat'l. Lab.
MA-044:	Monotectic and Syntectic Alloys Dr. C.Y. Ang, Northrop Corp.
MA-060:	Interface Marking in Crystals Prof. H.C. Gatos, MIT
MA-070:	Zero-G Processing of Magnets Dr. D.J. Larson, Grumman Corp.
MA-085:	Crystal Growth from the Vapor Phase Prof. H. Wiedemeier, Rensselaer Poly. Inst.
MA-131:	Sodium Chloride-Lithium Fluoride Eutectic Prof. A.S. Yue, UCLA
MA-150:	Multiple Material Melting USSR
	Cooperative Experiment
MA-028:	Crystal Growth in Space Dr. M.D. Lind, Rockwell Science Center

Experiment MA-011 will combine the efforts of several groups that have been active in the SRT program to perform separations of cells in closed tubes filled with stationary separation media. The primary samples will be human lymphocytes, a class of white blood cells that control much of the human body's immune responses to disease, and human kidney cells, some of which produce an enzyme called urokinase which is effective in removing blood clots from veins and arteries when administered in large doses. The kidney cell separation was proposed by Abbott Laboratories, which is attempting to develop processes to produce urokinase on a large enough scale for routine medical use. In addition, the performance of the apparatus will be tested using an artificial mixture of human and animal red blood cells made up to provide an accurately calibrated test pattern, and the same mixture will be used to perform a second test of the isotachophoresis technique used in the Skylab demonstration mentioned above.

The other electrophoresis experiment, MA-014, was proposed by the Max Plank Institute for Biochemistry and is being developed by the German Government. This experiment will perform separations in a continuously flowing medium, using a method that the Max Planck Institute has been developing to prepare biological materials in useful quantities. Samples of lymphocytes and red blood cells similar to those in the NASA experiment will be separated, and in addition the German experiment will process samples of the types of bone marrow cells that are responsible for producing red blood cells. A successful separation of the latter would contribute to work in progress at the Institute on transplantation of bone marrow to treat leukemia, radiation sickness, and other conditions in which red blood cell production is impaired.

Finally, experiment MA-028 will investigate a method of growing crystals of relatively insoluble substances by allowing two soluble chemicals to diffuse into each other in water to form the crystal material. Development costs are being shared by NASA and the Rockwell International Corporation; this is the first case of industrial cost-sharing that has occurred in space processing flight experimentation.

c. Supporting Research and Technology Program. It was pointed out above that the space processing program has probable already secured most of the returns that can be obtained from a straightforward search for new ideas. The extensive list of known application prospects has been discussed in some detail in the reports of the USRA committees [12] and the Space Shuttle Payload Planning Working Group [16], and together they provide a picture of the potential for space processing that is reasonably accurate. Because the number of available interesting ideas is large, the SRT program is composed of a

correspondingly large number of relatively small projects, as the summary given in the historical section indicates. This mode of operation has been convenient while the program's immediate objectives were largely exploratory, but it has inevitably caused some dispersion of effort. During the period when the space processing program will be making its preparations for utilization of the Shuttle/Spacelab system, it is felt that it will be appropriate to seek a greater concentration of SRT effort on issues that directly affect what will be done in the early years of the Shuttle's flight program.

Since development of general purpose equipment is planned for the Shuttle and Spacelab, the most important issues for the SRT program are clearly ones that concern the implementation of general processing techniques rather than the feasibility of particular products. In fact, all but a few of the product applications suggested so far depend essentially on just four categories of basic processes:

(1) Convectionless directional solidification.

(2) Containerless processing.

(3) Electrophoretic separation.

(4) Liquid and vapor diffusion.

Regardless of the products that may become important in the future, one can be sure that these processes will remain important in space processing applications. Therefore, it is believed that questions regarding their range of applicability, technology problems involved in their development, and extensions or refinements of control in their use are the subjects that the SRT program should emphasize. The basic features of each type of process and the research and development questions considered most important for each are discussed below:

(1) The central idea in what is called convectionless directional solidification processes is the attainment of very detailed control over the production of solid materials from melts. Weightlessness appears to make such control feasible because it can be used to suppress the random effects of convection, so the heat and mass transport effects that govern solidification become highly predictable. In most practical applications considered so far, control is exercised by producing a prescribed unidirectional temperature gradient in the melt so that solidification proceeds at a controlled and preferably constant rate. Applications of this type of process tend to revolve around

production of highly perfect crystals, very homogeneous materials, or highly uniform heterogeneous structures. Among these are crystal growth from the melt by the Bridgman, Czochralski, and floating zone methods (the latter two of which partake of containerless processing as well) and the production of controlled structures in eutectic and other alloys.

The degree of control that was available in the Skylab multipurpose furnace experiments based on this principle was relatively crude because the furnace temperature could not be programmed to provide constant solidification rates. Dispite this, experiments M559 and M563 showed that convectionless solidification could produce high homogeneity, and experiment M562 provided some encouraging indications regarding improvements in crystal perfection. In experiment M564 a more continuous rod-like eutectic structure was produced in the NaCl-NaF eutectic than had previously been obtained on the ground, which was somewhat unexpected because stable eutectic solidification requires a constant growth rate. The relatively high viscosity of the alkali halide melt may have made it relatively insensitive to instability. On the other hand the lamellar copper-aluminum eutectic used in experiment M566 was evidently quite sensitive in this respect since its structure was not substantially improved. Thus the available evidence suggests that absence of convection can have some desirable effects on solidification processes but that precise control over thermal conditions is required to realize the more sophisticated types of applications that may have high value. It is believed that further work on convectionless directional solidification should involve the analysis of the detailed thermal requirements for high crystal perfection and precisely controlled alloy structures and development of means of meeting these requirements in space apparatus.

(2) The term "containerless processing" is applied to processes in which weightlessness is exploited to levitate samples of material or otherwise support them out of contact with foreign materials. Examples of straightforward levitation processes include the purification of refractory materials by evaporation of relatively volatile impurities and production of new types of glass by undercooling metal oxides that are susceptible to heterogeneous nucleation. Propositions for grain refinement and enhancement of ductility in tungsten and other metals also fall into this class. However, containerless processing also embraces cases where materials are used in configurations that would be mechanically unstable on earth. Skylab experiment M552 and the "containerless" electrophoresis suggestion mentioned in the historical section are examples, as well as floating zone melting and the more complex operations that would be needed to grow semiconductor crystals in the form of thin ribbons or sheets. Technology is now available to maintain levitated samples

in fixed positions with respect to the spacecraft that carry them and to perform simple heating and cooling operations. However, means of manipulating the shapes as well as the positions of levitated liquids and precisely controlling temperature distributions and rates of change need to be developed, and the development needs to be guided by realistic analysis of requirements for prospective applications.

(3) Electrophoretic separation processes may take many superficially different forms, but all are based on electrochemical effects that cause particles to take on electrical charges when suspended in aqueous solution. The nature of these charges is determined by the equilibrium between particle surfaces and ions in the solution, so that the charges are characteristic of the particles but also can be manipulated to some extent by changing the solution's composition. Forces can be applied to particles charged in this way by applying an electric field to the solution, and when this is done each particle will move along the direction of the field at a constant velocity such that drag forces exerted by the surrounding liquid are equal and opposite to the electric force on the particle. In general, therefore, each kind of particle suspended in a solution moves with a characteristic velocity determined partly by its chemical nature and partly by its size and shape when an electric field is applied, and particles that move at different velocities can be physically separated and separately collected.

Space flight conditions can benefit electrophoretic separation processes by suppressing convective effects in the solutions, but the main advantage appears to be that weightlessness makes it possible to apply these processes to heavy particles that could not be maintained in suspension by any means on the ground. This class of particles includes living human and animal cells, and several applications in medical research and therapeutic procedures have been proposed for pure preparations of particular types of cells. More recently, it has also been pointed out that a variety of important industrial processes, including paper making and oil recovery, depend in essential ways on the electrochemical properties of colloidal particles and could benefit from data obtainable by making measurements of the electrophoretic behavior of such particles in space.

Over the near term, the critical need for both types of application is to make systematic measurements of the electrophoretic mobilities of materials that are of interest to potential users. This is obvious in the case of the industrial applications, and development of a means for making some of the necessary measurements on the sounding rocket flights is planned. However, the same need exists for the medical and biological applications; there is little

doubt that NASA can develop Shuttle/Spacelab apparatus for preparative separation of any materials that are separable, and the really critical questions revolve around the separability of materials that may be important enough to justify the development effort. Some preliminary data will be obtained on white blood, bone marrow, and kidney cells in the two electrophoresis experiments scheduled for the ASTP mission and these experiments will also establish technology for future payloads. Systematic studies of the separability of biological materials will also be pursued by microscopic methods that are available on the ground, and if possible by sounding rocket experiments.

(4) Applications of liquid and vapor diffusion include crystal growth by vapor transport, as in Skylab experiment M556, crystal growth from supersaturated solutions, and other processes that depend on obtaining predictable material transport through temperature and/or composition gradients in weightless, convectionless fluids. Relatively long periods of free flight are required for such processes because diffusive material transport is intrisically rather slow. Extensive experimentation in this area will, therefore, have to wait for the Shuttle/Spacelab flight program. However, process development will be pursued in the interim period by theoretical studies based on thorough analysis of the data available from the relevant Skylab and ASTP experiments, and experiments within the restricted range of convectionless conditions that can be obtained on the ground.

d. Sounding Rocket Flights. Currently available sounding rocket vehicles such as the Aerobee 200 and Black Brant VC have enough lifting capacity to provide free flight times above the atmosphere up to 8 or 9 minutes for payload weights that would be useful for space processing experiments, and within the next 2 years the larger Aries vehicle is expected to become operational. Performance curves showing free flight times versus weights of useful payload equipment are given for these three vehicles in Figure VI-1.

It is clear from these data that payloads large enough to implement several processing experiments at a time could be carried on flights lasting more than 5 minutes, and it has been found that relatively simple control systems can limit the accelerations experienced in free flight to the order of 10^{-5} g. Surveys of scientists interested in space processing and analyses performed in house have also indicated that capabilities of this order could support a variety of worthwhile experiments in all of the basic process areas described above. For example, directional solidification experiments have been performed on metallic alloys at freezing rates on the order of centimeters per minute, and at the growth rates used on Skylab it would be possible to grow semiconductor crystals on the order of a millimeter thick. Containerless

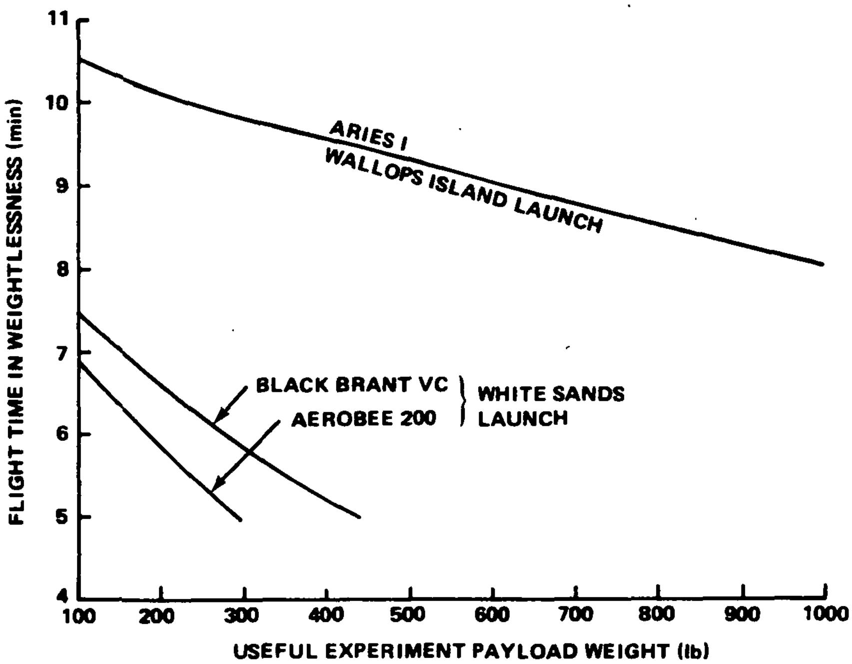

Figure VI-1. Sounding rocket capabilities.

processing systems could be tested in simulations using low temperature liquids, and one could do high temperature experiments that involved rapid heating or deployment of premelted material followed by limited manipulation and rapid quenching. Times of the order available on rockets would be long enough to measure the electrophoretic mobilities of virtually any class of particles or to test the performance of either of the devices to be flown on the ASTP mission, although not long enough to separate and collect significant amounts of material. Even in the field of diffusion processes it would be possible to measure the sensitivity of various potential experimental arrangements to small accelerations and to study transient effects such as the buildup of concentration gradients around a seed crystal placed in contact with a supersaturated solution.

Since it appears that sounding rockets can be of substantial experimental value during the period when no other flight opportunities are available, the space processing program is planning to carry out a regular series of experiment flights. Three vehicles of the Aerobee/Black Brant class will be flown in 1975, and as soon as possible thereafter the program will build up to three Aries flights per year. Experiments for these flights will be acquired in the manner that has been recommended for the Shuttle/Spacelab program, partly through open Announcements of Flight Opportunity and partly through ordinary

procurement processes. Payload development will also be analogous to what is intended for the Shuttle, in that apparatus will be designed for repeated use by different investigators, and it is expected that an inventory of equipment capable of implementing most feasible types of rocket experiments will be built up during the course of the program. It is expected that the flight opportunities provided by the sounding rockets will engage the interests of many organizations and individual investigators who otherwise would not participate in space processing. By performing experiments on the rocket flights they can obtain a preliminary view of what space methods can accomplish in their areas of interest without having to wait for the Shuttle program, and it is believed that this experience will increase the number of Shuttle users in the program's early years. Since payload operations for the rocket program will be analogous to those planned for space processing in the Shuttle program, it is also expected that they will be valuable for the development of payload management techniques that can be adapted to Shuttle operations.

e. Shuttle Payload Development. The principal technology issue confronting the space processing program for the remainder of the 1970's is that of designing and building capable payload equipment for the early years of the Shuttle and Spacelab flight programs. Since the experiment programs that these vehicles can support will be much larger than anything that has preceded them, it is expected that space processing as a technical discipline will pass through a period of rapid change during the first 2 or 3 years of Shuttle operations. Therefore, the program has adopted the technical strategy of laying requirements on the Shuttle and Spacelab systems to support large payloads that are foreseen for the late 1980's and 1990's but building enough equipment before the first Shuttle flight to provide only for early applied research operations. Thereafter, new equipment will be added to the program's inventory and old equipment will be modified as requirements develop.

Hitherto the emphasis in payload engineering for the Shuttle and Spacelab has been on defining general, long-range requirements and ensuring that they are adequately represented in design considerations for the vehicle systems. However, all major design decisions have been settled for the Shuttle, and the same will be true of the Spacelab after its Systems Requirements Review is held early in 1975. Beyond that point both vehicle systems will remain constant in their characteristics, and payload engineering will become a matter of designing equipment to meet experiment requirements within fixed system constraints.

To begin this process it will be necessary to define requirements specifically for the space processing program's initial complement of Shuttle payload equipment. These requirements will differ materially from those used

to portray long-range needs in the earlier phase of payload planning because they will correspond to the space processing user community's applied research objectives for the early 1980's. To compile the necessary information it is planned to assemble a group of expert consultants representative of prospective Shuttle users through an Announcement of Planning Opportunity to be issued in the late summer of 1974. Procurement of one or more Phase A payload study contracts will be initiated at about the same time.

During 1975 the assignment of the contracted Phase A study effort will be to combine requirements generated by the user group with interface data available on the Shuttle and Spacelab to derive conceptual designs for equipment that meets the requirements and also makes efficient use of the vehicles' resources. It is expected that the user group's thinking will evolve significantly as the study results reveal the engineering implications of their recommendations and that several revisions of the experiment requirements will be desirable. The Phase A activity will conclude with a Preliminary Requirements Review in the first quarter of 1976.

The results of the Phase A activity will be used to portray the prospective space processing capabilities of the Shuttle and Spacelab in an Announcement of Flight Opportunity and to construct a Statement of Work for a Phase B payload definition study. A group of experimenters will be selected from among the respondents and they will provide requirements data to the study contractor on their general disciplines, as well as on the specific experiments which they are under contract to implement. The study contractor will be charged with assembling detailed specifications for a sufficient initial complement of payload equipment, beginning with the items having the longest lead times. It is expected that the first approved specifications will be released and contracts let for design and construction of payload hardware in the second half of 1977 to meet flight dates in 1980.

The Announcement of Flight Opportunity will be renewed and additional experimenters selected yearly after 1976, and definition work on new equipment will proceed more or less continuously. It is expected that payload development will pass through a peak period just before Shuttle operations begin and then slacken to a lower, steady-state level when the inventory of available equipment becomes large enough to meet most ordinary experimental needs.

f. Shuttle Experiment Program. In the discussion of program goals and objectives given above, it was stated that NASA's goal is to develop beneficial applications of space processing but that the organizations that will deliver

such benefits operationally are expected to be private if delivery is made through commercial channels and governmental if through public ones. Some of the benefits envisioned are applied research results that may be available early in the 1980's, and thus it will be appropriate for NASA to try to involve organizations with permanent interests in such results in the earliest phases of the Shuttle experiment program. When it has been shown that space is a cost-effective setting for some of their work, it is expected that these organizations will invest in further activity in their own behalf. NASA's role in the early 1980's is, therefore, viewed as one of introducing the potential space processing community to space. This will be accomplished by making general-purpose facilities available for R&D work on the Shuttle and Spacelab, operating these space facilities to provide frequent, conveniently accessible flight opportunities, and sponsoring an experiment program designed to demonstrate the utility of space to potential user organizations. It is expected that the results of the NASA experiment program will contribute valuably to the branches of materials technology discussed in other sections of this report and that the basic technology established by NASA experiments and equipment development will materially reduce initial investment costs for other organizations wishing to undertake work in space processing.

Beyond this early phase, it is not easy to foresee the course of development in the Shuttle/Spacelab era. Conceivably space R&D techniques could prove so attractive that a large volume of user traffic would develop in a few years, leaving NASA to act as an operator of spacecraft and perhaps a developer of advanced equipment technology. However, it seems more likely that NASA will have to foster and encourage a gradaully increasing level of user activity throughout the 1980's and must look to later years for non-NASA traffic to generate the majority of space processing payloads. Pilot manufacturing operations for the first space products that may be invented will probably also call for heavy NASA involvement because of their inevitably high content of new space technology.

4. FLIGHT MISSION SUMMARY

A summary schedule for the space flights discussed in other sections of this report is given in Table VI-3. Only flights that have carried or are scheduled to carry space processing experiments are included. The characteristics of the Apollo, Skylab, and ASTP missions are well known, but the sounding rocket and Shuttle space processing missions call for a few specific comments.

TABLE VI-3. SPACE PROCESSING FLIGHT MISSION SUMMARY

	CY 1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
Apollo		14	16, 17										
Skylab				2, 3, 4									
ASTP						1							
Sounding Rockets Black Brant/ Aerobee						3	–	–	–	–	–		
Aries							3	3	3	3	3		
Shuttle/Spacelab											1	2	4

Note: ◯ Indicates Approval

a. Sounding Rocket Missions. It should be noted that the sounding rocket schedule shown in Table VI-3 is for a baseline program that may be materially modified in execution. At present, the plan is to conduct only 1 year of operations with the Aerobee/Black Brant class of vehicles because the Aries system is expected to become operational by 1976 and it is felt that its large payload capacity will lower the launch cost chargeable to each individual experiment. However, the choice of vehicles for each year's operations will be based on cost effectiveness for the size of the experiment program planned for that year, and the choices may vary from year to year. Therefore, the schedule shown should be taken as an index of the general level of activity planned for the rocket program and not as a firm commitment to those specific vehicles and numbers of launches.

b. Shuttle/Spacelab Program. The schedule given in Table VI-3 indicates the equivalent numbers of dedicated Shuttle/Spacelab missions listed for space processing in the NASA Mission Model but should not be taken to mean that all space processing payloads will fly on dedicated missions. In fact, as noted in the preceding section of this report, it is believed that most space processing payloads will share Shuttle flights with equipment carried for other types of experiments.

5. PROGRAM AND MISSION FUNDING

Actual and projected funding for space processing SRT and flight experiments for 1973-1980 are plotted in Figure VI-2. It should be noted that OMSF was responsible for the total program through FY-73, after which it was transferred to the Office of Applications (OA). However, although OA thereby became the Sponsoring Program Office for the Skylab and ASTP experiments, funding and management of the experiment development projects and postflight analyses continued to be an OMSF function, as it is for all experiments on those missions. OA will fund all future programmatic activities.

6. COST BENEFIT/COST EFFECTIVENESS ACTIVITIES

Scientists and engineers have suggested a wide variety of space processing ideas for which there is reasonable technical justification in the sense that novel or improved results should be achievable through the use of methods made possible by space flight. However, the economic justifications for the product applications covered by these ideas are only approximately known at best, and in some cases they are purely speculative. NASA has sponsored two contracted studies involving the economics of space processing and has recently initiated a third. These are summarized below, after which some conclusions are offered regarding the present status of the cost benefit/cost effectiveness problem and directions for further work.

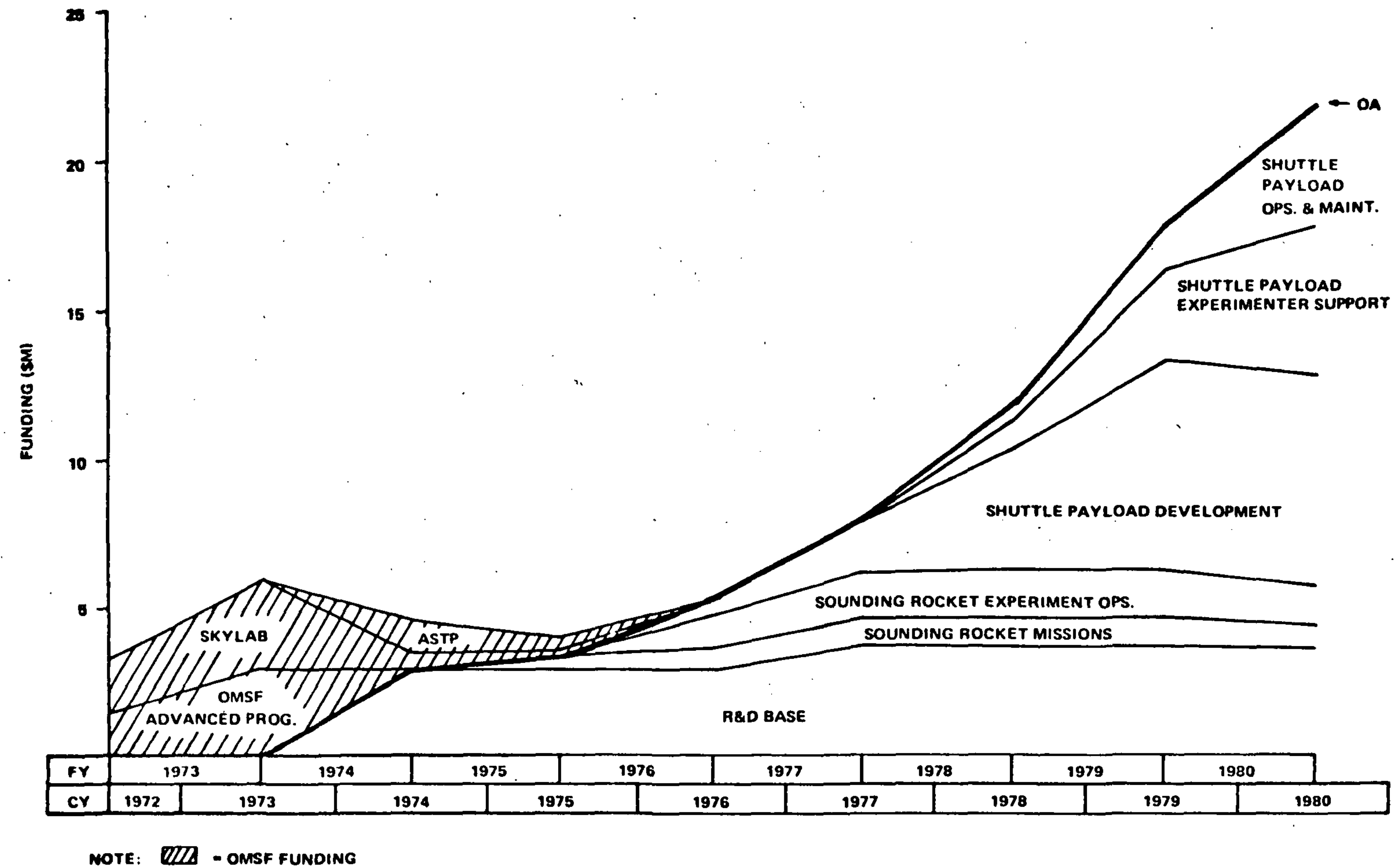

Figure VI-2. Space processing program funding trend (planning).

a. <u>Study for Identification of Beneficial Uses of Space</u>. The "BUS Study," as it came to be called, was conceived as an intensive and systematic repetition of the effort that had been made by NASA personnel in the late 1960's to define industrial interests in space processing. It was performed by the General Electric Company's Space Division beginning in 1972, and its stated objective was "to devise and exercise a methodology which would gain and maintain the interest and participation of non-aerospace organizations in identifying specific products, processes and services of value to the public" [22].

During the first phase of the study the contractor conducted an intensive program of interviews and followup meetings, contacting 80 industrial, academic, and government organizations and eliciting 120 suggestions for space activity affecting the respondents' interests. About 20 percent of the ideas suggested had enough apparent technical justification to warrant further consideration, and 12 ideas were selected for more complete technical and economic evaluation. None of these was completely novel in its technical basis, but all of the selected ideas involved material interests of the organizations proposing them. The analysis of these ideas included definition of the specific technical problems that should be addressed by space techniques to bring them to fruition, and evaluation of the direct and indirect benefits that might be achieved in the event of successful development and commercialization.

The analyses were preliminary in nature and were performed, for the most part, by personnel of the proposing organizations, under subcontracts to the G.E. Space Division. In some cases it was possible to point to attractive market potentials. For example, it was estimated that if space processing proved to be the key to manufacturing single-grain eutectic turbine buckets that could raise the inlet temperatures of jet engines by 150° C, then the increase in engine performance could be worth as much as $300M per year in airline revenue at 1972 fuel prices. On the other hand, no estimates could be made within the limits of the contract for the possible effects of competing technology or the cost implications of converting existing aircraft to the new engine technology. Moreover, the study had no detailed information on the costs of space operations available to it. The level of detail achieved in the other analyses was similar; in 4 of the 12 cases it was not possible to make specific benefit estimates and in the others the estimates ran from $5M to $100M per year.

In the second phase of the study [23] Space Division personnel worked with employees of the proposing organizations to lay out illustrative development plans for four of the ideas that seemed to have reasonably straightforward

commercial applications. These studies considered alternative approaches, worked out the development strategies expected to be most efficient, and laid out schedules and decision milestones for each. In general, the controlling factors in each plan were taken to be the technical requirements for development, and it was assumed that the space systems involved in each plan could perform whatever was required. It was estimated that a feasibility demonstration for each product would require time on two to four Shuttle flights and preparation of between 40 and 70 samples. In one case, an idea for producing ductile tungsten X-ray targets of superior quality by levitation heat treating, the planning effort showed that a valid feasibility test could be performed on the ground, and this was initiated as an SRT project.

The third and concluding phase of the study was initiated early this year. It will develop representative business plans for three space products, based on the development planning studies of the preceding phase and using the business planning methods that are normal in commercial manufacturing industry.

b. Economic Analysis of Crystal Growth in Space. This study was performed by the General Electric Company's Space Sciences Laboratory and members of the economics faculty of Drexel University. It comprised a straightforward attempt at technical and economic analysis of the prospects for growth of single crystals of electronic materials in space, and it surveyed future applications of crystal materials that are commercially important now, as well as products associated with emerging electronic technology [24]. Economic models of future electronic materials businesses were built on the basis of the structures of current businesses, and systematic market forecasts were constructed from analyses of businesses that use such materials.

It was concluded that space processing could be profitable only for products of advanced technology, for which the value added by processing tends to be high. The most promising product seemed to be garnet crystals for magnetic bubble computer memories, because a market of the order of $1 billion per year could be forecast for the 1980's. On the other hand, it was realized that there were manifold uncertainties associated with the feasibility of the product, competition from other technologies, and lack of firm data on costs of space operations, in addition to the approximations involved in long-range market forecasting.

c. Analysis of Space Manufacturing Costs. Three representative space products in the fields of metallurgy, electronic materials, and biological preparations will be considered in this new study, which is being performed by

Auburn University. Potential markets and market shares will be estimated, but in this case a detailed analysis of the structure of manufacturing costs will be attempted for the three products. The central feature of the analysis will be a set of manufacturing cost estimates for the parts of the production process that are carried out on the ground, using conventional methods based on plant layouts, labor cost formulae, etc. These costs, which can be estimated quite accurately, will be accounted for separately from the space operations costs, so the overall estimates can be refined when better data become available on the latter. In addition, it should be possible to base estimates of marketing and distribution costs on the ground processing costs using normal estimating factors, thereby avoiding the distortions of cost structure that could be caused by including the large and inaccurately known surcharge associated with space operations.

d. Conclusions and Plans for Further Work. The experience with economic analysis of space processing applications suggests that methods for cost benefit evaluation have not yet progressed far enough to provide reliable guidance regarding the justification for individual products, although they can provide some general principles. It is clear, for example, that the costs of space operations and investment in space processing equipment must be amortized by the value added to products by the processing steps that are performed in space, since the total selling price has to cover profit and non-space costs as well. Therefore, the cost structures, and estimates of prices and added values are, at best, very approximate.

For the time being the most promising route to further progress seems to be along the line of generating more accurate cost information. It is hoped that the Auburn University study can provide a framework within which the knowledge of manufacturing and overhead costs for ground processing can be refined. In addition, the Space Shuttle and Spacelab programs have now progressed far enough that useful estimates of space operations costs should be possible for conceptual designs of reasonable processes. Further cost studies in both areas should, therefore, yield good information on the minimum levels of price, added value, and sales volume requires for profitability.

The question of whether these minimum levels can be met in the markets that will exist when space manufacturing becomes possible is a good deal more open and will probably remain so for some years. About the best that apparently can be expected is that continuing forecasting effort at an appropriate level will provide information about the available methods and the capabilities of contractors in the field so that estimates of increasing reliability can be obtained as the market opens.

7. INSTITUTIONAL ARRANGEMENTS

At present NASA is the only U.S. agency that is conducting a space processing program, and its relations with other domestic organizations are purely through contracted research and development activities. Two programs that call for special mention are the research program at the National Bureau of Standards and consulting arrangements with the Universities Space Research Association described in preceding sections of this report.

In the international field, NASA has maintained close informal relations with the space processing activity conducted by the European Space Research Organization (ESRO) and has provided detailed information on space processing requirements to the Spacelab Program through the NASA/ESRO Joint User Requirements Group. In addition, NASA performed two Multipurpose Furnace experiments on Skylab under Letters of Agreement with sponsoring agencies of the Belgian and Japanese Governments and will carry a German electrophoresis experiment and a Russian Multipurpose Furnace experiment on the ASTP mission under similar agreements with the German Federal Republic and the Soviet Union.

Recently, it has become apparent that the levels of space processing efforts of ESRO and the European national space programs are increasing and may lead to an expansion of the cooperative activity with NASA. Measures of cooperation being considered at present include solicitation of foreign experiment proposals for the sounding rocket program, joint planning of a space processing payload and experiment program for the first Spacelab flight in 1980, and possibly, adoption of international standards for the features of space processing equipment design that affect integration of apparatus items within payloads.

It is also hoped that substantial cooperative effort will develop between NASA and U.S. industrial concerns, in which private industry will undertake space processing activities in its own behalf. The first small-scale instance of such activity is the MA-028 experiment for the ASTP mission, in which development costs are being shared by NASA and the Rockwell International Corporation. The response elicited by the user contacts made in the Beneficial Uses of Space Study described previously seems to offer ground for optimism about the amount of participation that can be developed when NASA can offer firm flight opportunities, and an appropriate level of marketing activity is planned in conjunction with the sounding rocket program. This activity is expected to develop contacts and procedures for a more ambitious effort when the lead time to available Shuttle flights comes within the range that industrial users consider practical.

8. REFERENCES

1. Manufacturing Technology Unique to Zero Gravity Environment. Unnumbered publication of NASA-George C. Marshall Space Flight Center, Nov. 1, 1968.

2. Space Processing and Manufacturing. Report No. MS-69-1, NASA-George C. Marshall Space Flight Center, Oct. 21, 1968.

3. Bannister, T.C.: Heat Flow and Convection Demonstration (Apollo 14). NASA Report No. TM X-64735, George C. Marshall Space Flight Center, Mar. 29, 1973.

4. McKannan, E.C.; Krupnick, A.C.; Griffin, R.N.; and McCreight, L.R.: Electrophoresis Separation in Space — Apollo 14. NASA Report No. TM X-64611, George C. Marshall Space Flight Center, Aug. 29, 1971.

5. Yates, I.C., Jr.: Apollo 14 Composite Casting Demonstration. NASA Report No. TM X-64641, George C. Marshall Space Flight Center, Mar. 1972.

6. Snyder, R.S.: Electrophoresis Demonstration on Apollo 16. NASA Report No. TM X-64724, George C. Marshall Space Flight Center, Nov. 1972.

7. Bannister, T.C.; Grodzka, P.G.; Spradley, L.W.; Bourgeois, S.V.; Hedden, R.O.; and Facemire, B.R.: Apollo 17 Heat Flow and Convection Experiments, Final Data Analyses Results. NASA Report No. TM X-64772, George C. Marshall Space Flight Center, July 16, 1973.

8. Bredt, J.H.: New Space Processing Experiments for the Skylab Mission. Paper presented at the 23rd International Astronautical Congress, Vienna, Austria, Oct. 8-15, 1972.

9. Final Reports on Space Processing Skylab Experiments: M512 facility accommodating experiments M551, M552, M553, M479; M518 facility accommodating experiments M556-M566.

10. Final Reports on Space Processing Skylab Science Demonstrations: Diffusions in Liquids; Ice Melting; Liquid Floating Zone, TV 101; Immiscible Liquids, TV 102; Liquid Films, TV 103; Rochelle Salt Growth, TV 105; Deposition of Silver Crystals, TV 106; Fluid Mechanics, TV 107; Charged Particle Mobility, TV 117.

11. Final Report of the American Institute of Biological Sciences Space Electrophoresis Panel (currently in publication).

12. Space Processing as Related to (1) Fluid Mechanics and Heat Transfer, (2) Containerless Processing, (3) Solidification of Metals and Semiconductors, (4) Preparation of Glasses and Ceramic Materials, (5) Electrophoretic Chemical and Biochemical Separation Processes. Apr. 15, 1974.

13. Reference Earth Orbital Research and Applications Investigations. NASA Handbook NHB 7150.1, (8 volumes), Jan. 15, 1971.

14. Reference Earth Orbital Research and Applications Investigations; Vol. VI, Materials Science and Manufacturing. NASA Handbook NHB 7150.1, Jan. 15, 1971.

15. Hammel, R.L. et al.: Requirements and Concepts for Materials Science and Manufacturing in Space Payload Equipment Study. Final Report on NASA Contract No. NAS8-28938, TRW Systems Group, July 1973.

16. Bredt, J.H. et al.: Final Report of the Space Shuttle Payload Planning Working Groups; Vol. 9, Materials Processing and Space Manufacturing. Unnumbered report published by NASA Goddard Space Flight Center, May 1973.

17. The 1973 NASA Payload Model. NASA George C. Marshall Space Flight Center, Oct. 1973.

18. Shuttle Sortie Payload Descriptions, Volume II. NASA George C. Marshall Space Flight Center, Oct. 1973.

19. Summarized NASA/ESRO Payload Descriptions, Sortie Payloads. NASA George C. Marshall Space Flight Center, Oct. 1973.

20. Hammel, R.L. et al.: Space Processing Applications Payload Equipment Study. Final Report on continuation of NASA Contract No. NAS8-28938, in press.

21. Bendix Aerospace Systems Division: Automated Space Processing Payload Equipment Study. NASA Contract No. NAS8-30741 (contract in progress).

22. Bloom, H.L. et al.: Study for Identification of Beneficial Uses of Space. Final Report on NASA Contract No. NAS8-28179, General Electric Co. Space Division, Dec. 10, 1972.

23. Bloom, H.L. et al.: Study for Identification of Beneficial Uses of Space (Phase II). Final Report on continuation of NASA Contract No. NAS8-28179, General Electric Co. Space Division, Nov. 1, 1973.

24. Ulrich, D.R.; Chung, A.M.; Yan, C.S.; and McCreight, L.R.: Economic Analysis of Crystal Growth in Space. Final Report on NASA Contract No. NAS8-27942, General Electric Co. Space Sciences Laboratory, July 1972.

CHAPTER VII. FUTURE APPLICATIONS

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER VII. FUTURE APPLICATIONS

1. HISTORY

In principal, any application of space systems or space technology which exists today is "history" with regards to future applications. The purpose of the future applications activity is to conceive, evaluate and, as appropriate, initiate studies and supporting research and development and to define new systems and technology which have social, economic, environmental, political, or defense benefits to the United States, as well as for all mankind.

The first, and probably the most well-known, application of space technology outside the aerospace industry is in the area of national defense. This technology, however, rapidly brought on the use of space and space systems to greatly advance worldwide communications. Not only did it provide new capabilities which had not been available, such as real-time worldwide TV transmissions, but it revolutionized the communications thinking and worldwide communications and electronics industries.

A spin-off, technology and systems wise, of space technology communications was the second major application, improved and new navigation systems. These new capabilities manifested themselves in two forms; first, the guidance and computer/electronics technology yielded inertial navigation systems and, second, the use of satellites provided a new form of worldwide navigation which was not possible prior to the advent of the space age.

Using space as a vantage point to view the earth first yielded, in addition to scientific knowledge and social amusement, applications in the form of meteorological reporting stations. At first, they were relatively simple and only monitored cloud cover; however, as the history books now record, not only has significant progress been made in understanding the weather phenomenon but also major strides have been made in our ability to model and predict it because of space weather systems such as Nimbus and Tiros.

Although some of our current "applications" are still in their infancy, by definition they are not considered "future applications" in the context of the 1974 applications summer study. These emerging applications are earth resources, earth and ocean physics applications, and space processing. As we all recognize, each of these applications is in their early stage of development and use; therefore, major strides can be expected in improving and expanding their applications, based on today's "concepts" and "technology." Again, by definition these applications are not considered future applications.

For the purpose of this summer study, "future applications" are quantum jumps in concepts or technology "breakthroughs" in the above mentioned areas or new ideas for the use of space systems or its technologies that can be applied for the benefit of the United States.

One future application area that is currently underway within NASA deals with the energy problem that faces our Nation and the world today. This activity was initiated as a "future application" item over a year ago and will be discussed in detail later. Other areas of application will emerge and it is the hope that, through the efforts of the summer study, general direction and possibly specific areas will be identified.

2. GOALS AND OBJECTIVES

The goals of the NASA future applications activity are to:

a. Anticipate, through working with others, future national and international needs that might be served through the use of space systems and technology, as well as understand the relative implications of their utilization.

b. Understand the potentials of advances in space systems and the associated technology for accomplishing new and future missions and objectives that this Nation may choose to adopt.

The objectives of the NASA future applications activity during the next 5 years is to add both breadth and depth to the program in order to better understand the potentials and benefits to be derived from space systems and their respective technologies. The focal point of this effort will be a comprehensive annual report delineating the potential role and benefits (social, economic, etc.) to be derived in general as well as specific future applications and to present recommended implementation plans for administrative consideration.

3. PROGRAM SUMMARY

The major future application activity initiated during this year has addressed the energy problem facing the Nation and the world at large. In structuring the energy program within the available resource authorization, NASA has endeavored to take into account also the Government-wide plans and programs for research and development (R&D) now being developed and implemented. The NASA program is intended to complement those plans and programs, as well as NASA's on-going research and development work related to energy generation and management.

NASA's FY-74 energy-related R&D comprises work in a variety of technical fields in which technology developed for space and aeronautics has useful applications to energy needs and problems on earth. In functional terms, the specific research and development projects, discussed in the Appendix volume and summarized below, include work in solar energy utilization, including wind energy systems; energy conversion, transmission and storage; transportation systems; and energy and environment conservation. NASA R&D programs in aeronautics and space which are directly related to energy include remote sensing applied to energy resources, fuel conservation in aeronautics, energy conversion and storage, and space and nuclear technology. The transfer to the private sector of aeronautical and space technology applicable to energy needs is another way in which NASA is making significant contributions in energy research and development.

Brief summaries of the work underway are reported here. In the Appendices volume greater detail of the individual projects is given.

a. Solar Energy Utilization. NASA projects directed to the near-term use of solar energy include a demonstration test at the Marshall Space Flight Center of a residential solar heating and cooling unit (which will be "on-line" by June of this year); the planned use of a large (50,000 ft^2) office building to be constructed at the Langley Research Center (LaRC), Hampton, Virginia, as a solar heating and cooling systems testbed; and a technology program at the Lewis Research Center (LRC) to advance the state-of-the-art of the components and subsystems for solar heating and cooling systems. All of these efforts are being carried forward in close cooperation with the National Science Foundation (NSF).

Work on solar energy utilization that could have longer range significance includes technical and economic studies of some of the components of space-based (satellite) systems in which solar energy would be collected and converted to electricity in space and transmitted to earth by microwave beams. In one study the use of solar cells for producing electricity in space will be considered, while in a second study the possibility of a turbogenerator in space (operating on solar heat to generate electricity) will be explored.

Other efforts to explore the use of solar energy in its broadest meaning include a Lewis-sponsored study to be conducted by Ohio's Agricultural Research and Development Center on the growth of crops which could be converted by several commercially available processes into clean fuels. This specific study has as its objective the determination of which species of crops would offer the highest net energy yield per unit cost. Also included under the broad category of solar energy is a joint NASA-NSF study to design and test wind-electric generating systems using advanced technology and modern systems approaches.

b. Energy Conversion, Transmission and Storage. In an extension of the R&D work the Lewis Research Center performed for spacecraft power generators, that Center is working in cooperation with the Office of Coal Research, Department of the Interior (USDI), to do preliminary engineering design, systems studies and cost estimates on a system to increase the efficiency of steam power plants. The objective of this work is to assess the technical and economic advantages of a technique (using a potassium topping cycle) which would permit higher peak-cycle temperatures than permitted by more conventional steam systems, thereby potentially increasing overall plant efficiencies to a point where more than 40 percent more electrical power could be produced for a given quantity of fuel consumed.

To provide a base of objective reference data on a number of potential alternatives to conventional power conversion systems, NASA is conducting a study on a number of advanced systems. These include Open and Closed Cycle Gas Turbine, Advanced Steam Rankine, Magnetohydrodynamics (MHD), and Fuel Cells. Use of coal, coal oil, coal gas and methanol will be considered in suitable combination with appropriate combustion techniques. That study is being carried out under cooperative arrangements with NSF and the Office of Coal Research.

To test the feasibility of transmitting major amounts of energy at reasonable efficiencies by microwave beams, NASA has undertaken a 5-year program which will encompass a theoretical investigation of the theory of microwave energy transmission, the design of critical components, the development of some of the subsystems, and verification tests of microwave energy transmission. If kilomegawatts of power can be transmitted by microwave over great distances with efficiencies as high as 90 percent, that could ultimately open the way to transmitting energy to earth from solar power plants in space or, alternatively, to the relaying of power by microwave transmission from point to point on earth.

In another project, NASA is studying methods of producing and using hydrogen as a nonpolluting medium for storage, transmission and utilization of energy.

c. Transportation Propulsion Systems. To alleviate the pollution caused by automobile and truck engines, recent trends in automotive design have had the effect of reducing efficiency, thereby increasing fuel consumption. NASA's efforts in transportation propulsion systems have as their goal the design of a low-polluting but high efficiency automotive propulsion system.

In one project, which began as part of an effort to reduce pollution due to aircraft engines and which is now conducted in cooperation with the Environmental Protection Agency (EPA), NASA's Jet Propulsion Laboratory (JPL), Pasadena, California, is investigating the potential of injecting relatively small quantities of hydrogen, generated from onboard gasoline, into the fuel-air system to improve the efficiency of an otherwise conventional internal combustion engine while at the same time reducing exhaust emissions below the 1977 Federal emission standards. Concept feasibility has been demonstrated both in the laboratory and in actual test cars equipped with bottled hydrogen. Future work will emphasize adapting the concept to practical usage and developing and perfecting the technology for onboard generation of hydrogen. American automobile companies and the Department of Transportation (DOT) are being kept informed of progress in this program.

Also in the area of automotive systems, the Lewis Research Center has established the Automotive Power Systems Office to direct technology development effort for EPA, including the management of several EPA contracts. That office is now focussing its efforts on demonstrating an automotive gas turbine engine having exhaust emissions that will meet 1977 Federal standards with increased economy. As part of this program, a baseline Chrysler gas turbine is presently undergoing detailed performance tests.

Analyses have shown that, for trucks and other "square-box" vehicles at road speeds of 50 mph, more than 50 percent of the engine power is used to overcome aerodynamic drag. As speeds increase, this power requirement increases sharply, in proportion to the velocity cubed. Tests are now underway at the NASA Flight Research Center, Edwards, California, to determine whether configuration changes would be a practical way of increasing "system" performance of such vehicles without significantly raising the costs or reducing cargo-carrying capacity. A joint effort with DOT for this work is in the planning stage.

d. Energy and Environment Conservation. Under the overall direction of the Department of Housing and Urban Development (HUD), a number of Federal agencies, including NASA, are participating in HUD's Modular Integrated Utility System (MIUS) program. The objective of that program is to demonstrate that utility services — electrical power, heating and cooling, potable water, liquid waste treatment and solid waste management — can be provided to a community of homes which become, to the maximum extent possible, a "closed system" requiring a minimum input of utility services and having a minimum output in terms of environmental impact.

Because of its experience in developing environmental control systems in manned spacecraft, the NASA Johnson Space Center (JSC), Houston, Texas, brings to the MIUS program its unique capabilities in a total systems approach to maintaining man in a "closed" or nearly closed environmental system.

The MIUS program is currently in its initial design, development, and test phase, with conceptual design studies having been completed for specific applications such as apartments, office buildings, hospitals, shopping centers, and residential communities. Following completion of this phase, several integrated utility systems will be demonstrated and evaluated in real-life situations.

To complement its efforts in the MIUS program, the Urban Systems Project Office at the Johnson Space Center is proceeding with work on gaseous fuel production by pyrolysis of municipal waste. The objective in this effort is to identify and evaluate optimum systems for the conversion of municipal refuse into clean fuels; such systems could be key elements in perfecting the MIUS concept.

Other projects related to municipal energy and environmental conservation include a project at the Lewis Research Center which in FY-75 will lead to a design for EPA of a prototype of a modified laser radar to detect and measure particulate and gaseous pollution in smokestack emissions. This project will be supplemented by a related project at the Lewis Center — carried out in cooperation with the Cleveland Air Pollution Control Board — to measure urban air contamination by use of a computerized trace-element "fingerprint" identification. In this latter project, operational tests will begin in FY-75.

Another project is at the Jet Propulsion Laboratory which has developed a new method of obtaining high quality water from sewage. This process uses activated carbon in the water as a settling agent and also as a clarifying filter. The system is unique in that the sewage sludge which settles out of the water is pyrolyzed, regenerating activated carbon.

This technology was derived from JPL work in improved lightweight insulation for solid rocket motors. Porous materials of various kinds, including activated carbon, were investigated. Commercial carbon was found to be unacceptable, so the conversion of organic wastes into carbon was investigated. These wastes were supplied by a riding stable adjacent to JPL and by the sewage system at Edwards Air Force Base. Very high quality carbon was obtained by the pyrolysis of these organic substances.

At the time this work was going on, JPL was preparing a study to automate the sewage treatment plant of the Los Angeles Municipal Sanitation Department. They were able to integrate the work done in both these areas and develop the Carbon Waste Water Treatment System. A small scale demonstration unit of this system has been tested at the Orange County (California) Sanitation District's Plant No. 1. Influent sewage is collected from the plant and processed through a standard filter to remove sticks, grit, etc. Activated carbon is added to the sewage to cause rapid settling. The water from the sewage is processed through a series of activated charcoal filters and then is released into the environment. The water is of high quality with over 95 percent of the oxygen-demanding wastes and 99 percent of the suspended solids removed. The sludge which remains is pumped into a pyrolysis unit and reactivated in carbon to be used in the filters and the settling basins. No biologically active sludge remains; only a sterile ash is left.

This process seems to have many potential applications, especially in processing water from canneries, munitions plants, mills, etc. The economics of the system appears to be good. The Orange County Sanitation District is applying to the EPA for a construction grant to gradually install this system in its plants, and they have estimated that as much as a 25 percent reduction in capital costs could be achieved.

e. <u>On-Going Programs in Aeronautics and Space Relevant to Energy.</u> The relationships of a number of NASA's main-line programs with energy generation and management are summarized in the Appendices volume. Included is a brief description of how the R&D work NASA is performing in the Earth Resources Survey (ERS) Program — using data from the first Earth Resources Technology Satellite (ERTS-1) and the Skylab Earth Resources Experiment Package (EREP) — can help to locate new sources of energy. With remote sensing it is possible, for example, to help explore for petroleum and geothermal areas, to detect subsurface fractures which control rockfalls in underground coal mines, and to monitor the results of strip mining and land reclamation.

Also included in the appendix related to this chapter is a section describing NASA's long-standing efforts in civil aviation which could lead to significant savings in the use of jet fuel. Those efforts include work on improving aircraft operating systems, aeronautical power plant R&D aimed at higher operating efficiencies, advanced aircraft design efforts which in the long term could lead to fuel savings of up to 30 percent over current aircraft, and work on advanced air transportation concepts such as hydrogen-fueled aircraft and lighter-than-air vehicles.

The Appendices volume further outlines NASA's on-going advanced research and technology work on space-related applications of solar cells and arrays, electrochemical energy storage and conversion devices, electrical power distribution, lightweight isotope power systems, low-temperature thermionic converters (to generate electricity from heat sources), magneto-hydrodynamic power generators, magnetics and cryophysics, laser power transmisson, and plasma (fusion and gas-core uranium) reactor research.

f. Examples of Energy-Related Technology Utilization. The appendix related to this chapter (in the Appendices volume) concludes with mention of three specific examples in which NASA-developed R&D is being applied through the NASA Technology Utilization Program in nonaerospace energy-related uses. Fostering such projects from NASA's line programs is an integral part of NASA's basic charter.

In the first example, a prototype scrap metal separator employing a "ferrofluid" technique invented and patented by NASA (for potential use in launch vehicle propellant orientation) has been built and is being tested. This prototype system is expected to lead to commercialization by Avco Corporation as an economical way of separating various nonferrous scrap metals.

The second space spin-off related to energy is a nickel-zinc battery developed for space applications by the McDonnell Douglas Corporation and NASA. It has the potential of energy density three times that of conventional lead-acid batteries, with half the weight at a comparable price.

Finally, the experience of the Kennedy Space Center, Cape Canaveral, Fla., in handling hazardous propellants is being used in a program to assist the New York City Fire Department in developing a risk management and facilities certification methodology for the safe handling of liquid natural gas (LNG). When developed, this management technology is expected to have widespread use in the Nation's port cities now faced with LNG facilities safety problems.

4. PROGRAM FUNDING

Table VII-1 summarizes the current levels of funding for the NASA space technology applications activities in energy problem solving. Some are direct appropriations for this program ($2 M in FY-74); others are funds from the regular NASA appropriation (about $5 M) and the largest part of the program is reimbursable ($5 M); i.e., NASA work paid for by other agencies. The total of $11 M is not a large sum of money compared to other segments of the

TABLE VII-1. SUMMARY FUNDING FOR PROJECTS IN ENERGY RESEARCH AND DEVELOPMENT FY-74 (THOUSANDS OF DOLLARS)

	FY-73 Funds	FY-74 Funds			Reimbursable Funds	Total
		Authorized In PL 93-74[a]	Other[b]	Total		
Solar-Electric Power Systems						
Space-Based Solar Power Conversion and Power Relay System Study	–	275	—	275	—	275
Earth-Based Solar-Thermal Power Conversion and Delivery Systems Studies	360	175	—	175	—	535
Solar Heating and Cooling						
Residential Building Solar Heating and Cooling	—	400	—	400	—	400
Full Scale Solar Collector Test Bed	470	—	—	—	—	470
Solar Heat and Cooling System Technology	470	—	—	—	—	470
Wind Electric Power Generation	—	—	—	—	865	865
Energy Conversion, Transmission and Storage						
Potassium Rankine Topping Cycle Study	—	—	132	132	1,200	1,332
Energy Conversion Alternatives Study	—	—	300	300	1,750	2,050
Microwave Energy Transmission and Reception	—	500	—	500	—	500
Survey of Hydrogen Production Methods and of its Potential for Replacing Fossill Fuels	65	270	—	270	—	335
Survey of High Energy Per Acre Crops	35	—	—	—	—	35
Transportation Propulsion Systems						
Hydrogen-Injection for Automobiles	—	—	1,465	1,465	300	1,765
Automotive Gas Turbines	—	—	392	392	200	592
Aerodynamic Drag of Large Road Vehicles	—	—	42	42	65	107
Energy and Environmental Conservation						
Modular Integrated Utility System (MIUS)	—	—	—	—	736	736
Development and Evaluation of Gaseous Fuel Production by Pyrolysis of Municipal Waste	—	380	—	380	—	380
Remote Sensing of Smokestack Pollution	—	—	112	112	—	112
Air Pollution Source Identification	—	—	250	250	—	250
Total	1,400	2,000	2,693	4,693	5,116	11,209

a. NASA Authorization Act, 1974, paragraph 1(a)(7).

b. Other NASA funds from regular NASA appropriations.

NASA program but it is significant and it supports some activities of potential major significance, such as the Modular Integrated Utility System and the hydrogen-injection for automobiles.

It is difficult to forecast the growth of this program because of its individual-project characteristics. We do anticipate a modest growth over the next few years and we anticipate that areas other than energy-related problems will become part of the program.

5. INSTITUTIONAL ARRANGEMENTS

The NASA authorizing legislation did not anticipate the changing public attitudes toward large investments in spaceflight nor the possibility (which has happened) that a large, highly-capable technological establishment would be created and then, as the major project, Apollo, was completed, be reduced in size. Many of the experiences, skills, and techniques developed for spaceflight are applicable to other problems facing society, pollution and energy being obvious ones. But the transition and the applications of these capabilities to new areas, whether by the aerospace industry or by NASA have not been easy. Some of the problems are clearly institutional; other agencies are chartered by their enabling legislation to budget for and manage the programs. Thus, the major part of the NASA program in energy-related technology is reimbursable, i.e., funded by other agencies, as shown in Section 4.

As the program summary shows, NASA has established effective working relationships with Federal (such as HUD), state, and local agencies.

CHAPTER VIII. THE SPACE TRANSPORTATION SYSTEM AND SPACELAB

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

CHAPTER VIII. THE SPACE TRANSPORTATION SYSTEM AND SPACELAB

1. INTRODUCTION

In the spring of 1972 the United States embarked on the development of a new Space Transportation System (STS). In contrast to the expendable systems used during the first two decades of the space program, the major elements of this new system would return to earth to be refurbished and reused many times. Since this new system was to serve the national need it would have sufficient overall performance to satisfy all of the projected requirements of both the civil and military programs. It would provide an opportunity not only to deliver spacecraft into orbit but to return to systems already in orbit to make repairs or modifications or to retrieve film and other data. The system would employ man, both to maximize its own utility and to serve the needs of the payload where his versatility and discretionary abilities would enhance the conduct of the mission. Since the basic vehicles were to be returned to earth for reuse they could similarly return instruments or spacecraft for major repair or updating. The new space transportation system would permit an entirely new approach to the effective use of space.

The basic vehicle in this system is the Shuttle. The total system, however, embraces an additional vehicle. It is a propulsive upper stage which will be carried within the Shuttle cargo bay, along with a spacecraft, and will be used to reach orbits beyond the capabilities of the Shuttle alone. This vehicle, the Tug, will be used to deliver satellites to geosynchronous orbit and beyond.

A complementary system, under development by the European Space Research Organization (ESRO), is known as Spacelab. It includes a pressurized module which can be carried in the cargo bay and provides a laboratory-like environment during Shuttle missions. It also provides a number of racks, or pallets, on which major instruments or other equipment can be mounted in the Shuttle cargo bay.

The Shuttle is scheduled to become operational for launches to the east from Cape Kennedy in 1980. Spacelab and an early version of the Tug will be available about a year later. Launches into high inclination orbit from Vandenburg Air Force Base are currently scheduled to begin in late 1982.

The following sections briefly discuss the major characteristics of these systems and illustrate their use. Also included is a section on man's role in space as it was demonstrated during the Apollo and Skylab programs and as it can be applied during the Shuttle era. A list of documents which contain detailed information is given in Section 6.

2. SPACE SHUTTLE SYSTEM

The Shuttle flight system is composed of the Orbiter, an external tank containing the ascent propellant to be used by the Orbiter main engines, and two solid-rocket boosters (Fig. VIII-1).

The Space Shuttle mission begins with the installation of the mission payload into the Orbiter payload bay. The payload will be checked out and serviced before installation and will remain in a quiescent state. Flight safety items for some payloads will be monitored by a caution and warning system. The two solid-rocket boosters and the three Orbiter main engines will be ignited at the completion of all prelaunch checkout (Fig. VIII-2). The two solid rockets are jettisoned after burnout and, by means of a parachute system, are recovered for reuse. The large hydrogen and oxygen tank will be jettisoned prior to placing the Shuttle Orbiter into orbit. The orbital maneuvering system of the Orbiter will then be used to obtain the desired orbit and for any subsequent maneuvers that may be required during the mission. The payload-bay doors located in the top of the Orbiter fuselage will open to expose the payload and the crew can then start payload operations. Current planning indicates the duration of the initial missions will extend up to 7 days. By adding consumables in mission kits, the duration may be extended to 30 days in future missions.

Upon completion of orbital operations, deorbiting maneuvers will be initiated. Entry into the earth's atmosphere will be made at a high angle of attack. At low altitude, horizontal flight attitude will be assumed for approach and execution of an aircraft-type landing. After the Orbiter has landed and undergone preliminary safing and securing, it will be removed to a facility for inspection, maintenance, limited servicing, and checkout for the next flight.

Assembly and checkout of the vehicle will begin with mating of solid rocket motor segments on the mobile launch platform. The external tank will be moved to the assembly area and mated to the two solid rockets. The Orbiter will be towed to the Vehicle Assembly Building (VAB), lifted into position, and mated with the large propellant tank to complete assembly of the Shuttle.

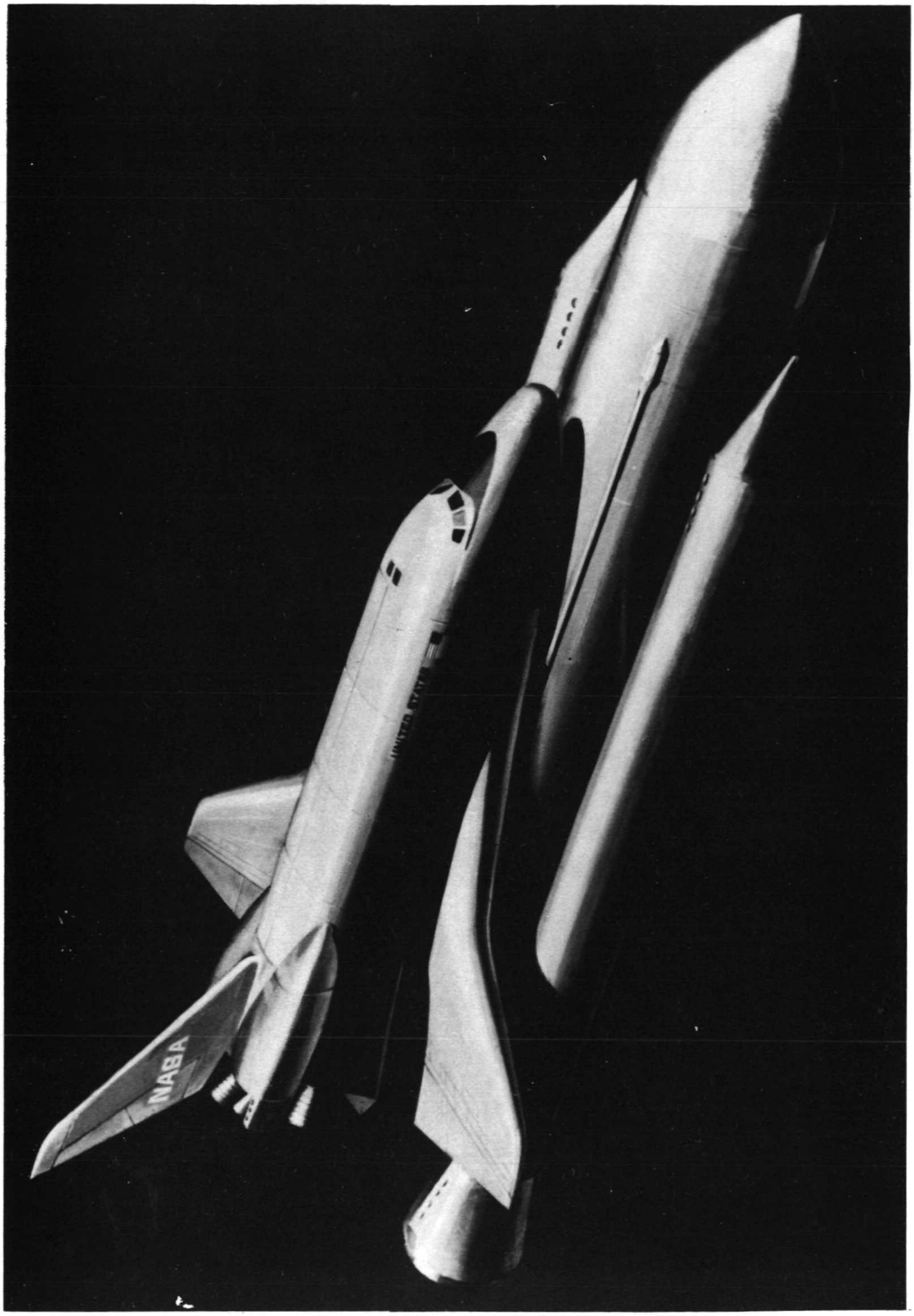

Figure VIII-1. The Space Shuttle.

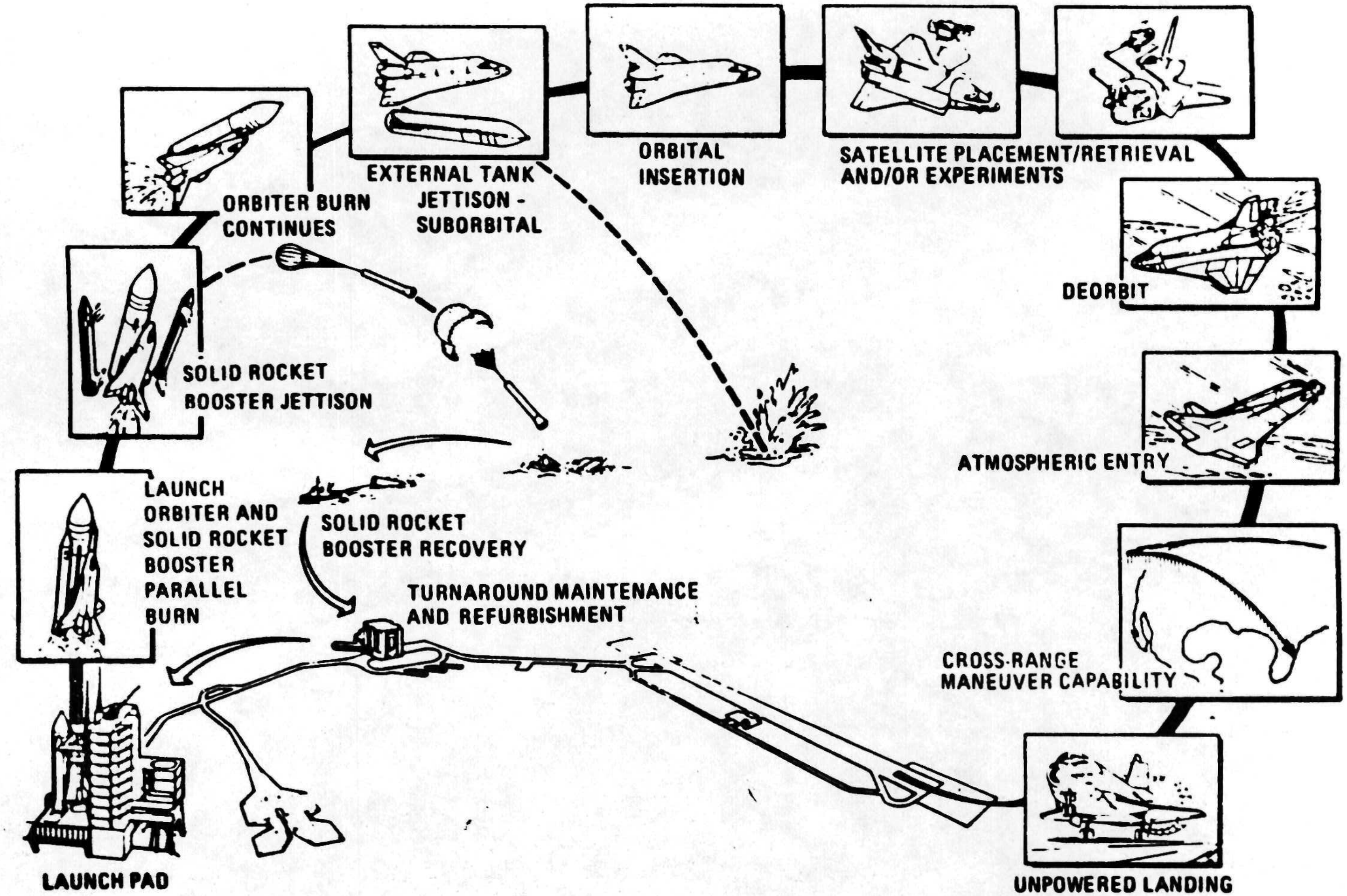

Figure VIII-2. Space Shuttle mission phases (typical).

After rollout of the vehicle to the launch pad, operational interfaces will be connected and countdown preparations will be completed with loading of cryogenics, crew ingress, and the final automatic countdown sequencing. Present planning provides for a 14-day, 160-hour turnaround from landing to lift-off, on a two-shift-day, five-day-week. This relatively short checkout period will be made possible through the use of an automated launch processing system being developed for the Shuttle. Consisting of display and control consoles, computers, data-transmission systems, and associated computer programs, this system will perform all essential ground operations, substantially reducing the time and manpower that was required on previous manned spacecraft launches.

a. Payload Accommodations. The Orbiter systems are being designed to handle various payloads and to support a variety of payload functions. The payload and mission specialist stations on the flight deck provide command and control facilities for payload operations required by the cognizant user. Remote control techniques can be employed from the ground, when desirable. The crew will be able to use a manipulator for remote operation of payloads or to remove and replace them in the cargo bay.

b. Performance. The performance capabilities of the Space Shuttle are dependent on the operational requirements established for each mission. The type of rendezvous technique, the payload pointing requirements, the operational constraints, length of mission, orbit transfer requirements, etc., determine the performance capability for any particular mission. Certain items of equipment, consumables, etc., which are mission unique must be considered as part of the total payload and, in planning for a particular mission, must be included as part of the payload weight.

The Orbiter cargo bay is an unobstructed cylindrical volume 15 feet in diameter and 60 feet in length for use of payloads and it can carry a maximum of 65,000 pounds into orbit. This delivery capability corresponds to a due-east launch from Cape Kennedy into a circular, low-earth orbit (Fig. VIII-3). For polar missions launched from Vandenberg Air Force Base, the corresponding delivery capability is 40,000 pounds; nominal payload landing weight is 32,000 pounds.

c. Crew. In normal operations, the personnel complement can vary from four to a maximum of seven. Commander, pilot, mission specialist, and a payload specialist comprise the basic crew. For missions requiring additional payload specialists, up to three more personnel can be carried. Living accommodations will be provided on the Orbiter's lower deck (Fig. VIII-4).

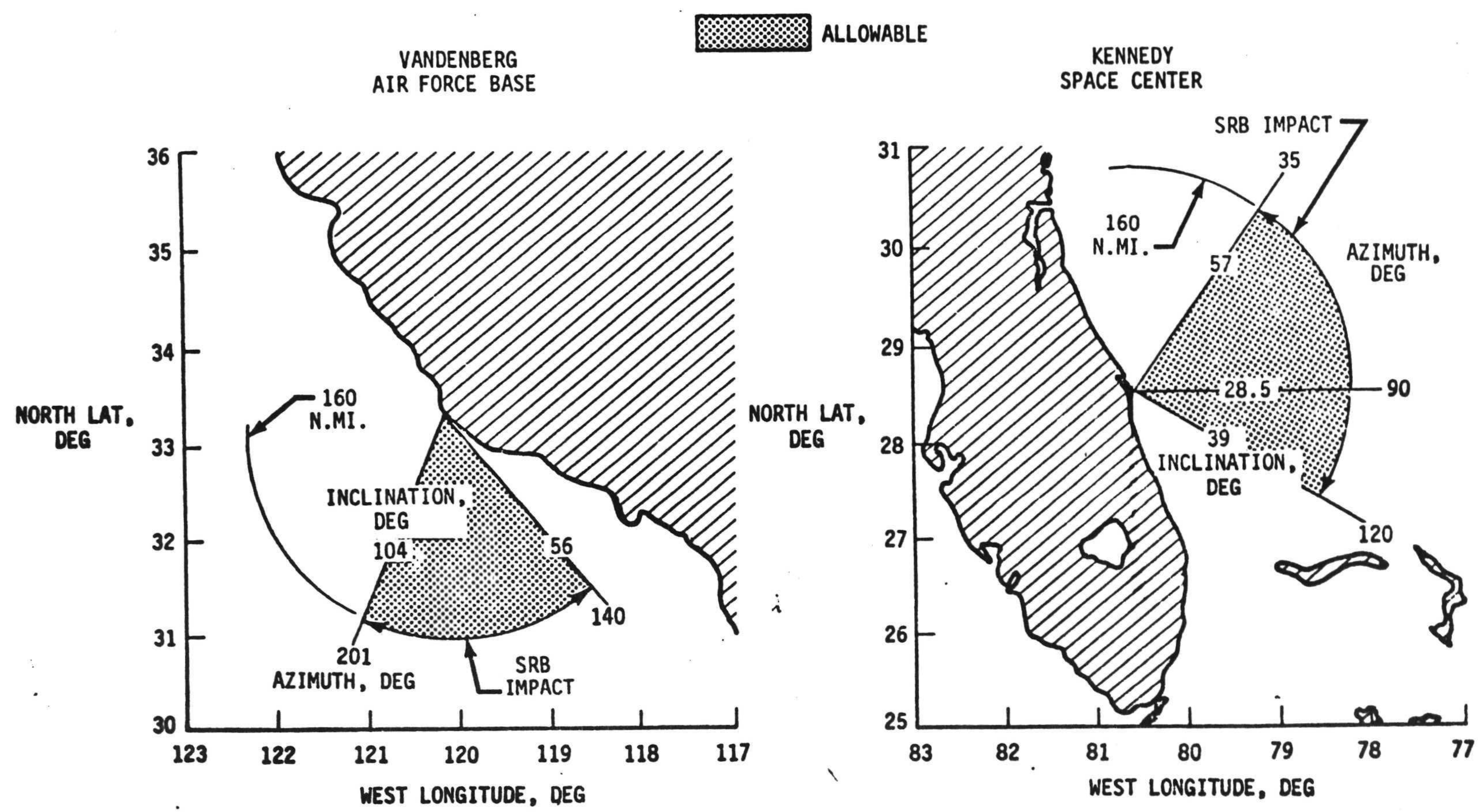

Figure VIII-3. Launch azimuth and inclination limits for Space Shuttle.

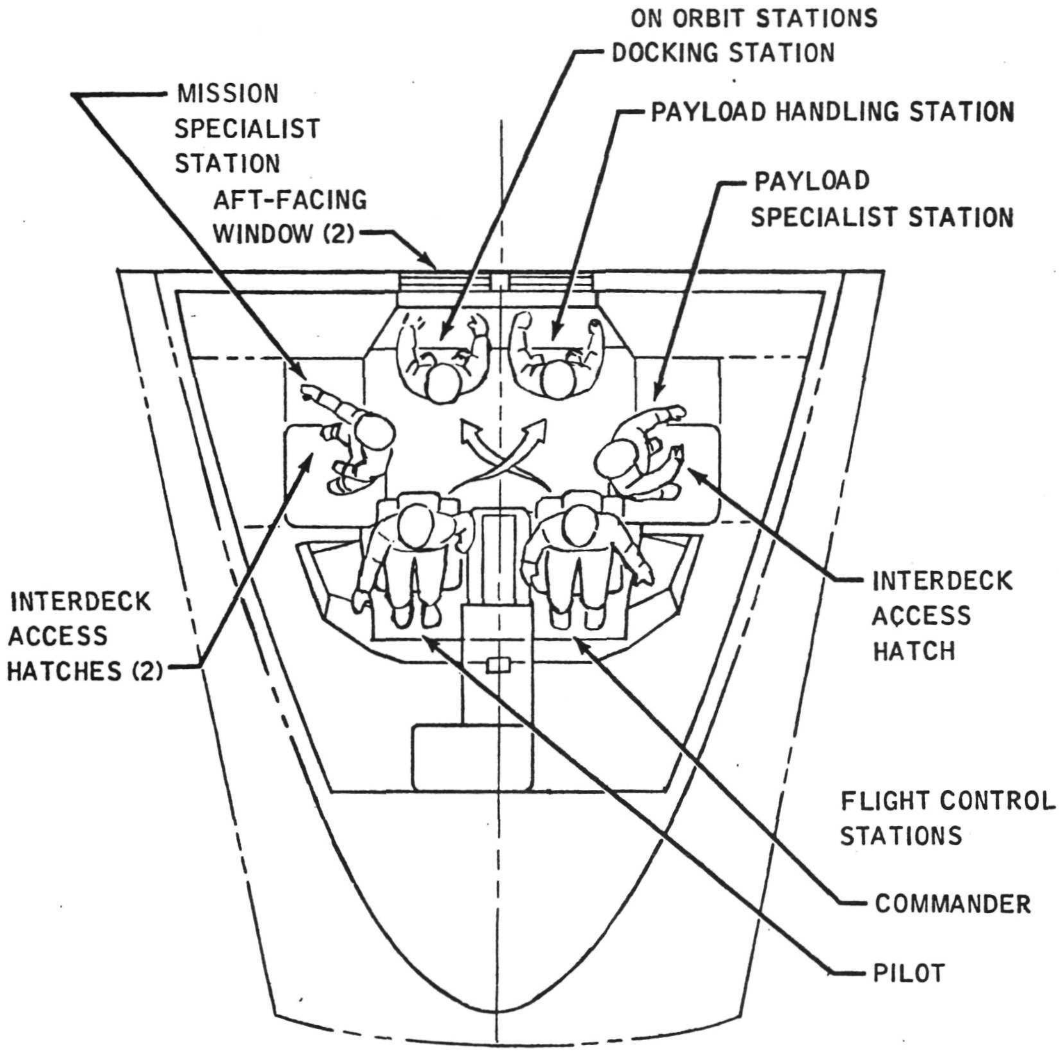

Figure VIII-4. Crew compartment: flight section crew stations.

d. Remote Manipulator System. The remote manipulator system which will be used to deploy and retrieve satellites or propulsion stages is operated from a station in the aft end of the upper deck in the Orbiter cabin (Fig. VIII-5). Windows provide visibility directly into the payload bay and out above the Orbiter cabin; visibility will be augmented with floodlights and a TV system.

For payload deployment, the manipulator will be engaged with the payload which is then released from its moorings. The manipulator will lift the payload out of the bay into space and release it; the Shuttle then will move off and stand by. Should the payload at that point fail to operate satisfactorily,

the option exists to reverse the deployment process, retrieve the payload, and return it to earth for repair. The procedure is exactly the same for recovery of a payload which has been in orbit for an extended period.

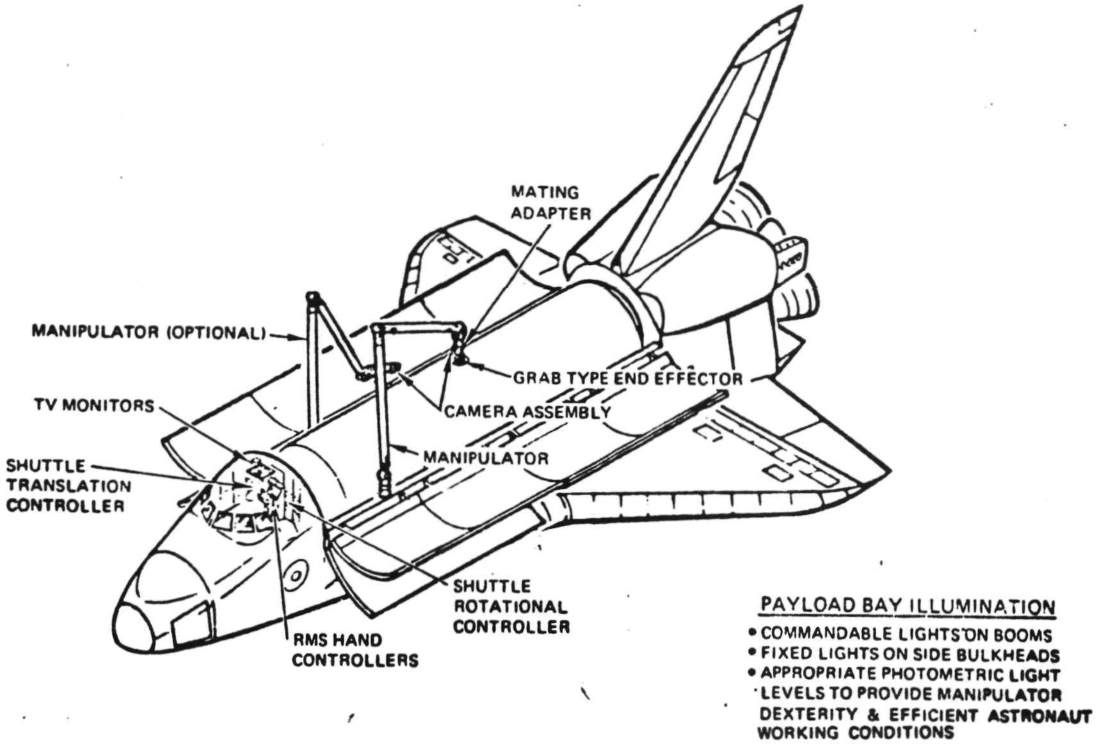

Figure VIII-5. Shuttle deployment/retrieval system.

This basic retrieval capability can be extended to include capability for servicing satellites on orbit. Spent or failed subsystems can be replaced and instrument packages can be changed.

The Shuttle's capabilities for retrieval of payloads and its use as a base for on-orbit servicing open up many possibilities for cost savings in the space program.

e. Communications. The Orbiter's communications system includes command and control, telemetry, and ranging capabilities between the Orbiter and a detached payload sufficient for safe deployment and retrieval operations. For attached payloads, hardwired communication is provided for voice, command and data exchange sufficient for caution and warning, and limited functional checks, and management of the interface between the payload and the

Orbiter. Uplink and downlink relay capabilities between ground and payload are also provided.

In addition, for Spacelab operations where the need exists for transmission of substantial amounts of data to the ground, the Orbiter wideband transmission system will send television or equivalent high rate data streams. Communication between the Orbiter and ground will be via the Space Tracking and Data Network (STDN) or the Tracking and Data Relay Satellite (TDRS) system. For the STDN system, the wideband transmission capability is 256 kbs, or one television channel of roughly commercial quality. When the TDRS is operational, it will replace a large portion of the STDN network of ground stations and will substantially expand the communications coverage. The Shuttle will then utilize the Ku band for wideband transmission, thereby increasing the size of the bit stream from 256 kbs to 50 Mbs without prohibitive increase in antenna size or complexity.

f. Power and Energy. The Space Shuttle Orbiter will provide payloads with an average of 1 kW of electrical power, with allowance for short-term peaks of 1.5 kW throughout all flight phases. When the Orbiter is not conducting critical maneuvers, one of the onboard fuel cells will be dedicated to payload use. For Spacelab missions, which are the primary ones requiring higher power levels, 7 kW average and 12 kW peak electrical power will be available most of the time on orbit.

The baseline electrical energy available to payloads from the Orbiter is being carried at 50 kW-h. This is adequate for Tug and free-flying satellite missions but most Spacelab missions will require installation of extra fuel cell reactant tanks beneath and outside of the payload bay envelope. The scar weight penalty to the Orbiter for this provision is quite low for flights not requiring the additional tank sets.

These power and energy resources provided by the Shuttle Orbiter will satisfy the needs of most 7-day Spacelab missions. For the relatively few projected Spacelab missions which have higher power and energy requirements, special payload-peculiar provisions will be made.

g. Active Thermal Control and Heat Rejection. Since the utilization of electrical energy generates heat which must be dissipated, payloads such as Spacelab which have relatively high electrical requirements must provide for active thermal control and rejection of heat into space. The Shuttle Orbiter will be able to handle payload-generated heat loads up to 8.5 kW (thermal) or approximately 30,000 Btu's per hour. This is sufficient for normal operations.

h. Pointing and Stabilization. Figure VIII-6 illustrates the concepts of pointing and stabilization. The Orbiter will be capable of pointing in any direction to an accuracy of ±1/2 degree. It can be stabilized at that pointing position within a deadband of ±1/10 degree. For greater accuracy, payload sensors, e.g., a telescope, can be mounted on a stabilized platform and operated in closed loop with the Orbiter guidance and control system. By such a technique, it should be possible to stabilize payload sensors to approximately ±1 arc second. This is directly analogous to the technique utilized on Skylab where the comparable accuracy was ±2.5 arc seconds.

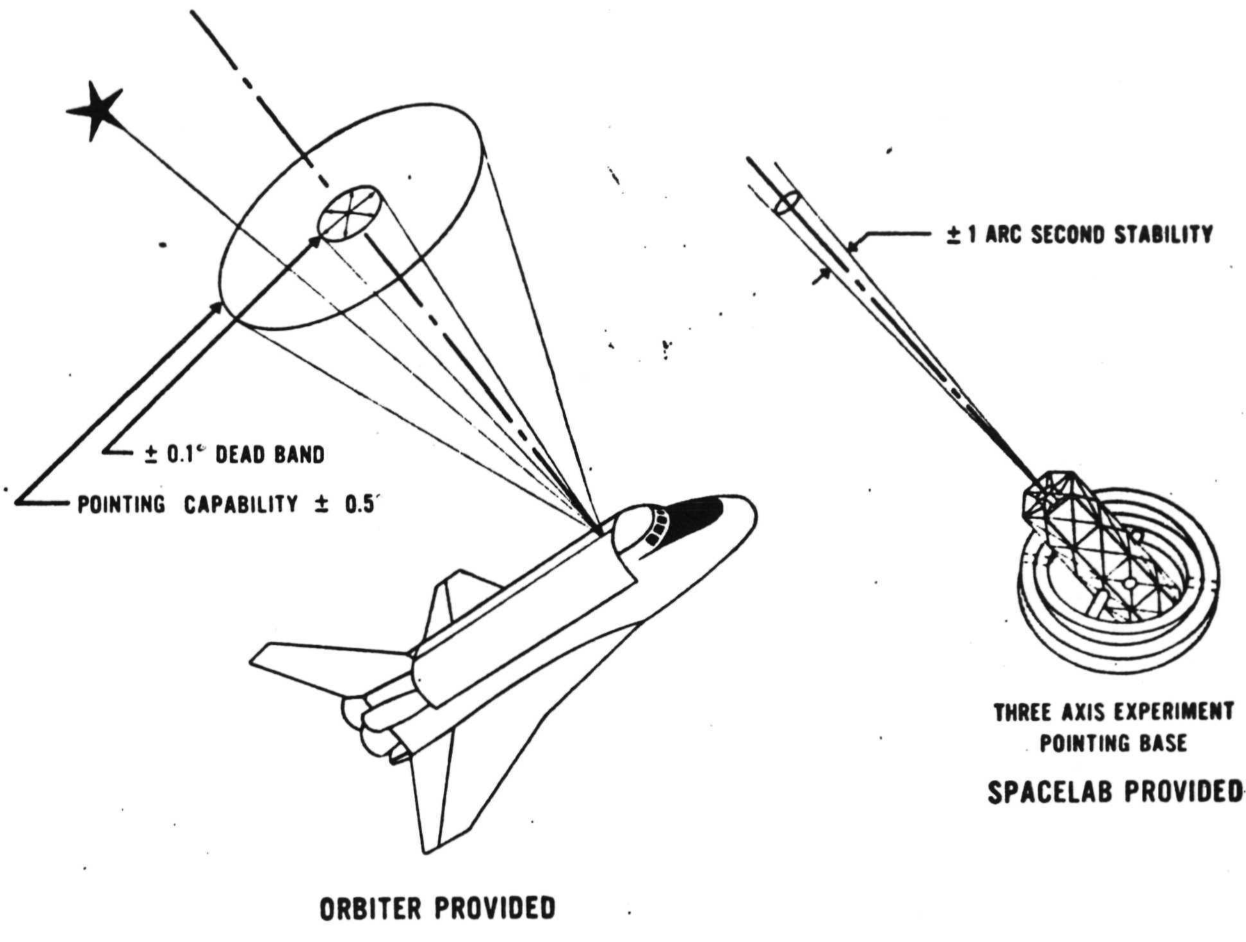

Figure VIII-6. Orbiter pointing and stabilization capabilities.

i. Summary. The Shuttle is a multipurpose, reusable launch, orbital, and reentry system. Its large cargo bay will accommodate all of the currently anticipated payloads of the 1980's. In addition to transportation, the Shuttle is

capable of providing power, thermal dissipation, communications, and pointing in support of payload operations for mission durations up to 30 days. The Shuttle provides payload transportation both into and out of orbit. Its crew and payload specialists are available to enhance mission effectiveness in those areas and activities where man's diverse capabilities can be employed. In combination with the Spacelab and Space Tug, the Space Shuttle will introduce an opportunity for an entirely new approach to space operations in the 1980's.

3. THE SPACE TUG

The Space Shuttle will be essentially a low altitude vehicle. About 40 percent of the projected U.S. spacecraft, however, require orbits beyond those which can be reached by the Shuttle alone. When the Shuttle program was started it was, therefore, recognized that a secondary propulsive vehicle would be required. This secondary vehicle, operating in conjunction with the Shuttle, will extend the capabilities of the Space Transportation System to geosynchronous orbit and beyond.

NASA and the Department of Defense (DOD) have been jointly pursuing the development of this Shuttle upper stage known as the Space Tug. A typical Space Tug mission is shown in Figure VIII-7. The vehicle is an unmanned stage that is transported to low-earth orbit in the cargo bay of the Shuttle Orbiter. It will provide the necessary increment of velocity beyond that which the Shuttle itself can impart to place spacecraft in their planned orbits or escape trajectories. Consistent with the philosophy of the STS, it will be recovered by the Shuttle and returned for repeated refurbishment and resue. In addition, through its planned capability to provide on-orbit payload servicing or payload retrieval, this stage will provide payload services beyond those which can be frunished by existing expendable stages. The Tug will, therefore, effectively extend the capability of the Shuttle for payloads falling outside the range of the Shuttle itself.

The performance capability of a typical Tug configuration presently under study for these various types of missions is compared with an existing expendable launch vehicle in Figure VIII-8. The payloads shown by dots are representative of those in the present NASA mission model. Projected performance of the Tug indicates that it will be able to deliver around 8,000 pounds of payload to geosynchronous orbit and return empty. It can go to orbit empty and retrieve 4,000 pounds or can carry 3,000 pounds up and retrieve 3,000 pounds on a single 7-day geosynchronous mission.

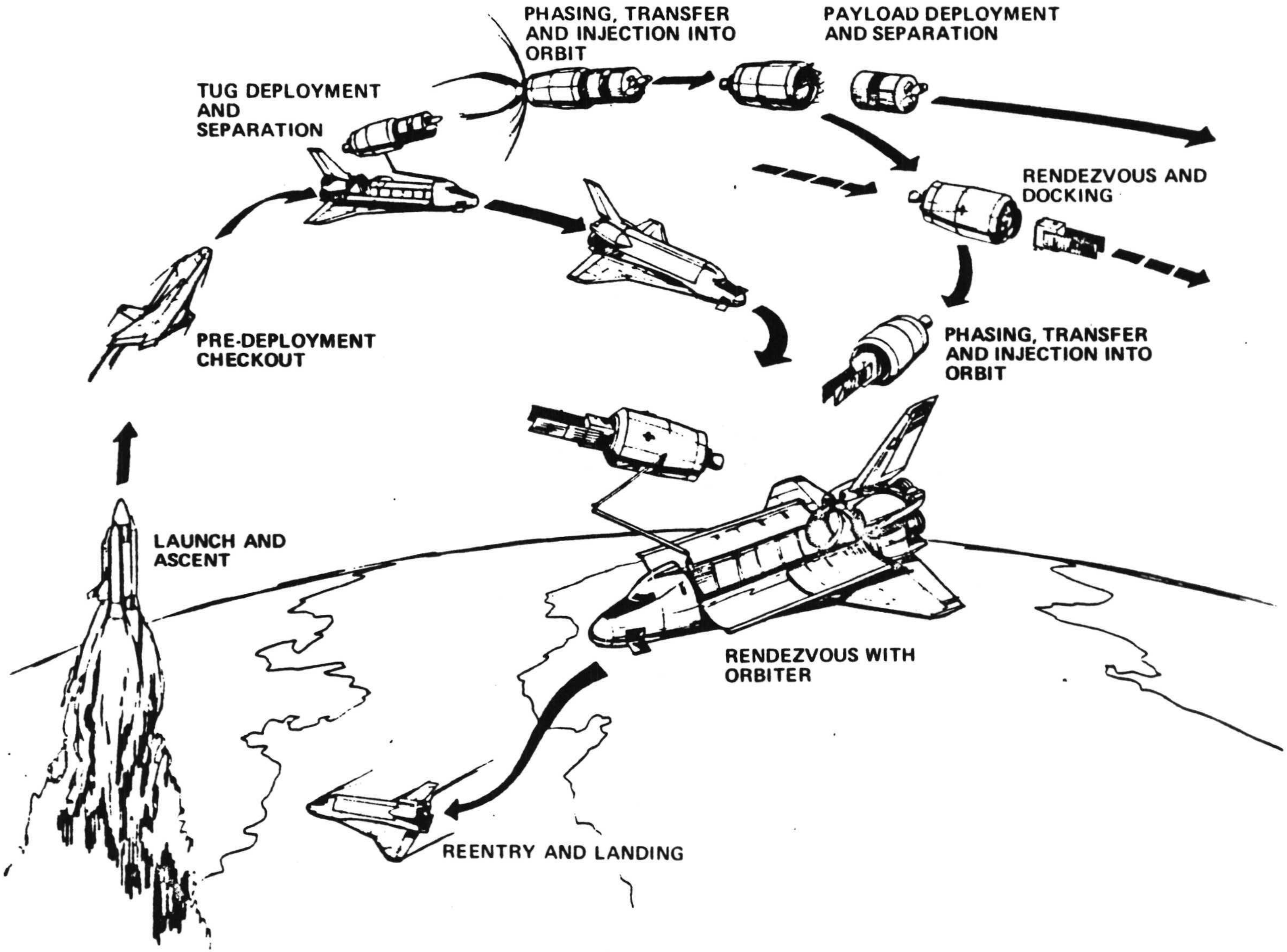

Figure VIII-7. Space Tug operations.

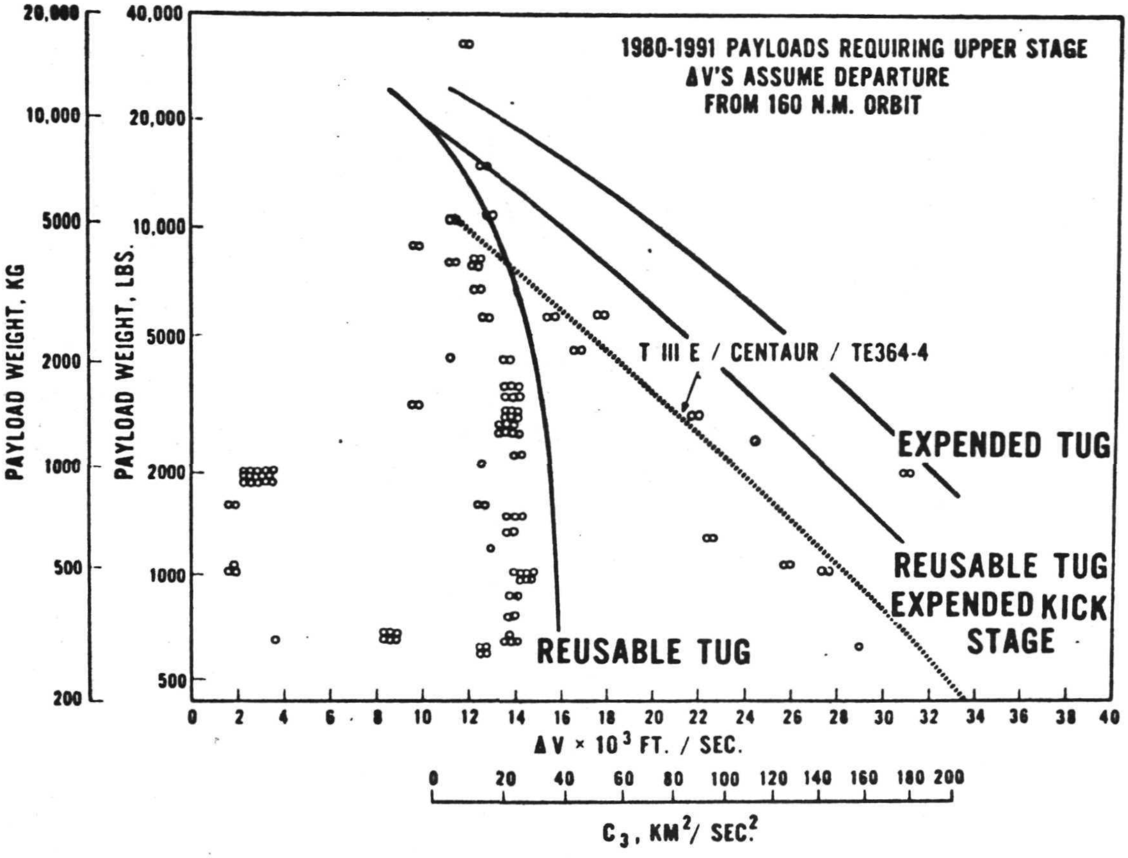

Figure VIII-8. Space Tug performance.

The reusable Tug with an expendable kick stage will be able to inject a spacecraft weighing around 3,000 pounds into a transplanetary trajectory with a $C_3 = 100\ km^2/sec^2$. The polar orbit capability is shown in Table VIII-1. The Tug can accommodate payloads, or combinations thereof, up to 14.5 feet in diameter and 25 feet long.

The Tug will be capable of performing a variety of classes of missions, as shown in Figure VIII-9 and described below:

a. The most obvious and the most common class will be the placement of spacecraft, either in orbit or in escape trajectories. Planning for Tug missions includes the launching, on a single Tug, of several spacecraft which are destined for compatible locations. Since the launch costs can be shared by several users, such multiple payload launches offer an opportunity for minimizing the transportation costs. Multiple launches must, of course, be compatible with overall capabilities of the Shuttle/Tug combination.

TABLE VIII-1. POLAR ORBIT CAPABILITY

Circular Orbit Altitude (n. mi.)	Round Trip Payload Weight	
	For WTR Launches (lb)	For ETR Launches (lb)
1000	20,000	3,000
5000	6,000	3,000
Escape (Delivery with Tug Return)	5,000	--

Notes: WTR — Western Test Range

ETR — Eastern Test Range

b. A second class of missions is that of payload retrieval. When a payload has failed in orbit, or when it is approaching the end of its operating life, the Tug can rendezvous and dock with it, return it to the Shuttle, and, hence to the ground. This class of missions also allows the physical return of mission data, e.g., film, samples exposed to the space environment, experiments, etc.

c. A third major class is the round trip mission; it may be one of two types. One involves the case where the operating time of the satellite is of sufficiently short duration and the importance of retrieving the satellite is sufficiently great to justify leaving the Tug attached while the satellite operates. A similar condition could exist if a spacecraft, upon being checked out in orbit, fails to operate. It could then be returned for correction of the problem and relaunch. The round trip capability can also be used following delivery of one spacecraft by pickup and return of one which has malfunctioned.

d. The fourth major class of missions is that in which the Tug visits but does not retrieve the spacecraft. Typical of this class is the servicing mission in which a servicing mechanism mounted on the Tug removes failed or expended modules from an orbiting spacecraft and replaces them with new modules. Such a mechanism would be designed to mate with the spacecraft to be serviced. Similar missions in this class would be those in which the Tug replenishes expendables on a spacecraft or retrieves recorded data or other materials.

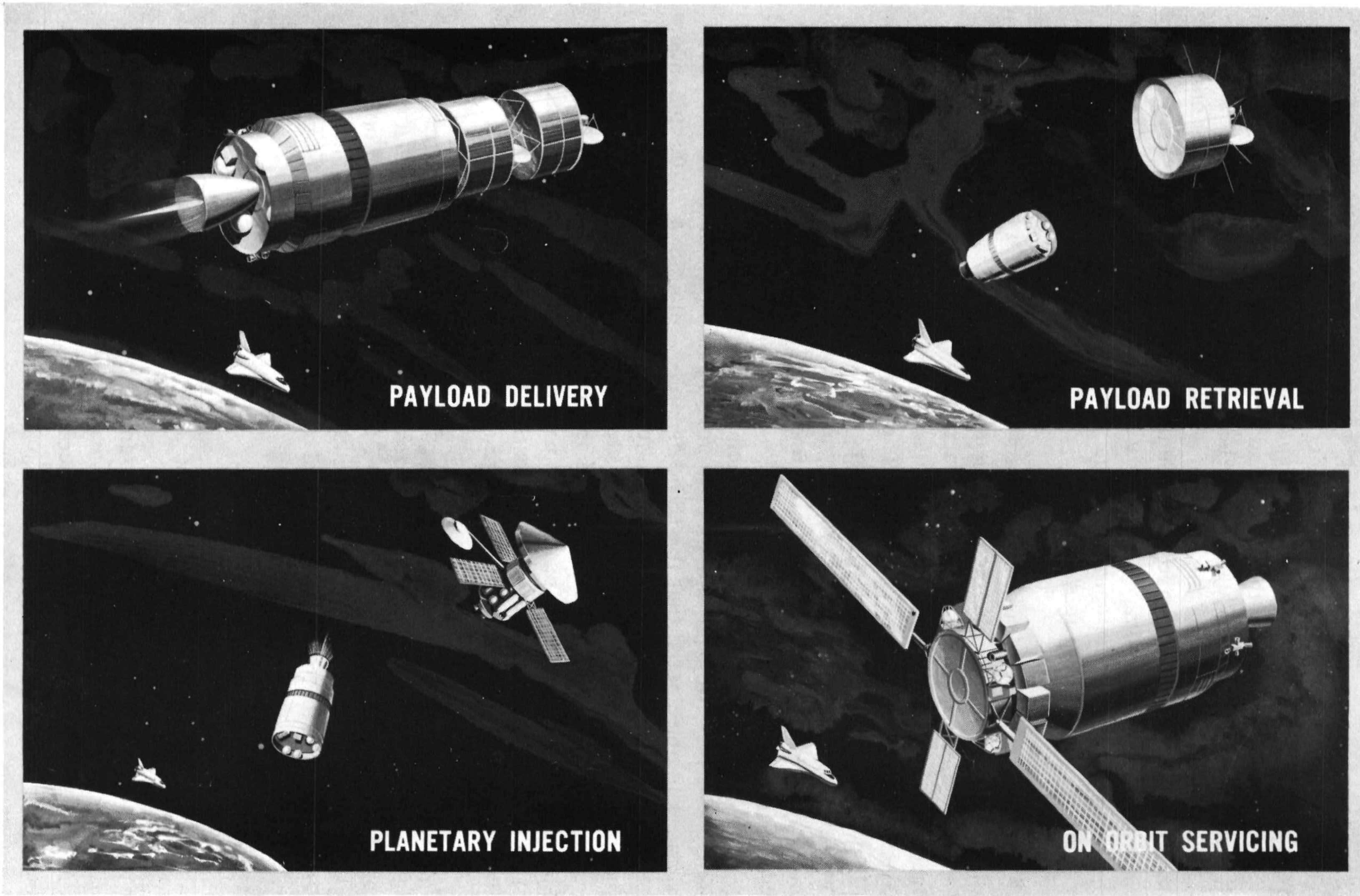

Figure VIII-9. Uses of Space Tug.

The Tug will be capable of providing a number of services which are not generally provided by current expendable launch vehicles. These include such things as electrical power to operate spacecraft systems, onboard data processing, communications with orbiter and ground, and perhaps payload checkout while attached to the Tug. They also include payload thermal control, whether by an active system on the Tug or by a passive method such as changing payload orientation with regard to the Sun. These services may also include precise spacecraft pointing or, with a special mechanism, imparting payload spinup. The converse of this operation, the spindown of a payload, could be performed by the same mechanism.

At the present time, the Tug program is proceeding in two major phases. The first consists of the development and use of an interim upper stage (IUS) vehicle having some of the capabilities required of a Tug. It will be developed and produced under the direction of the Space and Missile Systems Office (SAMSO) of the United States Air Force. The stages will be used by both NASA and the Department of Defense. NASA is providing to DOD the consolidated non-DOD user requirements and is working closely with DOD in the IUS development planning. The IUS is to be available for first flights late in 1980. The design will consist of an uprated version of an existing stage. It will have less delivery capability than is ultimately planned for the Tug and will have no retrieval capability. Although the specific performance of the IUS has not been established, it is anticipated that it will be capable of placing a 3,200 to 3,500 pound spacecraft into geosynchronous, equatorial orbit. As of now, no determination has been made as to whether or not the IUS will be retrievable by the Shuttle Orbiter and, hence, be refurbished and reused for later missions. This decision will be made as a part of the process of selecting the existing stage to be used as the basis for the IUS design; however, retrieval and reuse capability is not a prime requirement of the IUS.

The second major phase of the program will be the development and deployment of the Space Tug itself. This phase will be accomplished under the direction of the George C. Marshall Space Flight Center of NASA. The Tug will be available for first flights late in CY-83. It will be retrievable and reusable and will perform the missions and provide the services described earlier.

4. THE SPACELAB

The Shuttle is a space trucking system with flexibility to transport a variety of payloads but requiring supplemental apparatus to make it useful as a laboratory. To satisfy this need the Spacelab was conceived and has evolved to the concept presented here; a versatile, cost-effective laboratory designed to accommodate a great variety of experiments.

Concurrent with NASA's recognition of the need for a more effective space transportation system, the European space community, in response to an invitation by the President of the United States, initiated studies of how they could participate in the post-Apollo space program. After an in-depth study of the possible alternatives, the European Space Research Organization offered to design and build the Spacelab as a European-funded part of the Shuttle/Spacelab system. This offer was accepted and Spacelab design and development is now under way in Europe.

Spacelab is made up of two major elements, a pressurized module to house both equipment and operators in an earth-like atmosphere and an exposed structure called the pallet, on which sensors such as radars, radiometers, and telescopes could be mounted to operate in the space vacuum. Both of these elements mount in the Shuttle cargo bay as shown in Figure VIII-10; they may be used independently or in combination, as dictated by the mission.

The following example will explain the usefulness of the Spacelab. A satellite can be envisioned to survey worldwide sea state and with this data the safest and most economical routes of ships could be plotted. Preliminary work in ground laboratory and in aircraft flights has determined that such a system is feasible and it is now desired to test the system from orbital altitudes. The radar system includes two major antennas, externally mounted and free to radiate and receive data, and electronics to drive the antenna and to receive, process, and record data. The electronics are rack mounted and designed for air cooling. The orbital testing requires that the crew accompany the equipment to make adjustments and repairs and to investigate a variety of pulse shapes and frequencies. The Spacelab concept was designed with the intent of approaching ground laboratory flexibility to the highest possible degree to meet the needs of anticipated users. Thus, forced air cooling is used for electronic components, which are mounted in standard electronic racks designed to meet the g forces of launch and reentry. Power up to 5 kW is available in nominal commercial frequencies of 50 and 60 cycles, as well as aircraft/space standards (28 Vdc and 115 volt, 400 Hz). The payload crew, which may be comprised of both men and women, has access on orbit to the electronics comparable to that in a terrestrial laboratory. Should access to the antenna be required in orbit, and Orbiter crewman, wearing a spacesuit similar to that used on the lunar surface, could make repairs or adjustments to the antenna. A detailed listing of the Spacelab capabilities is given below:

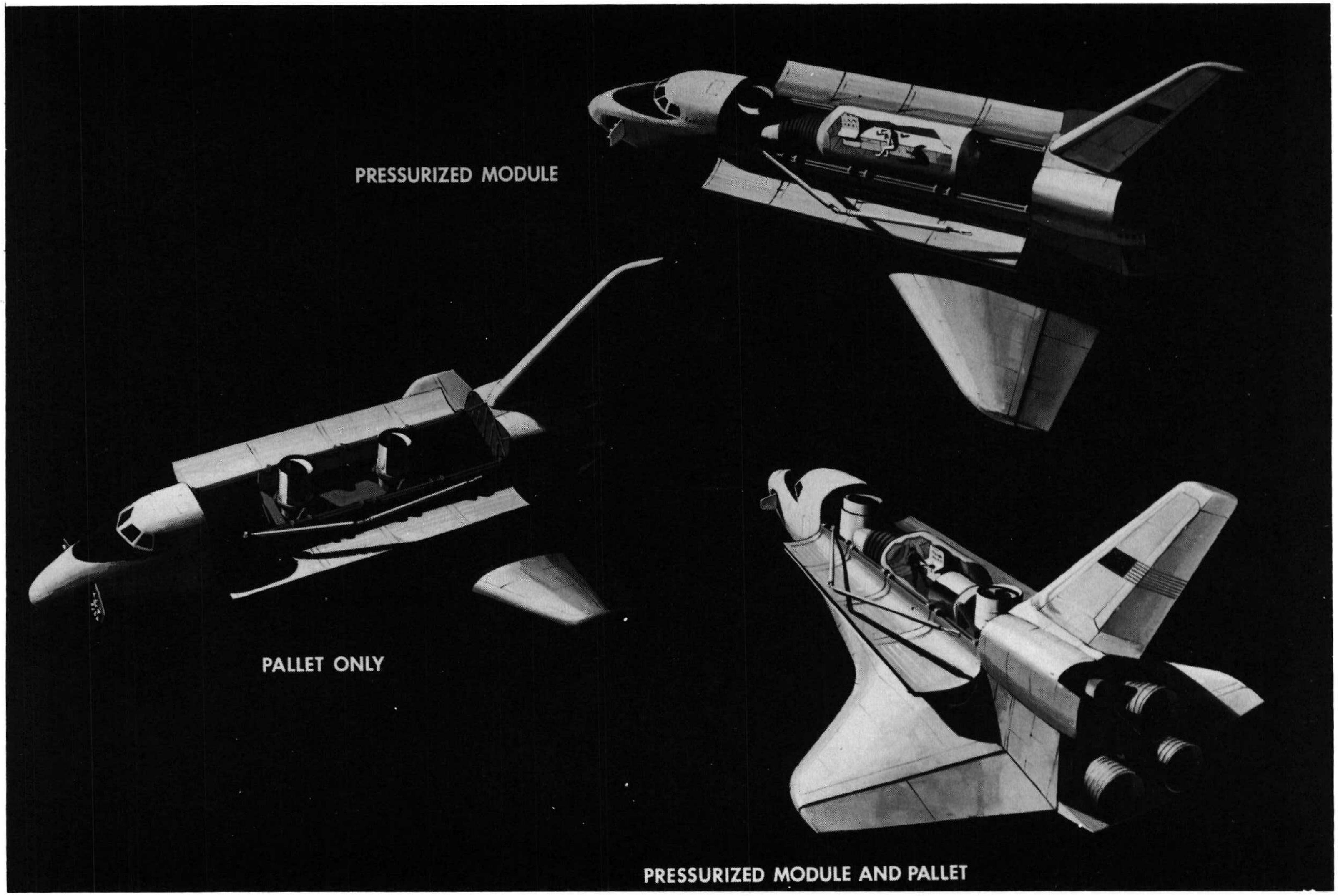

Figure VIII-10. The Spacelab.

Spacelab User Support Capability

Crew Size	1-4 Payload Specialists
Experiment Weight	4,400-22,000 lb (2,000-10,000 kg)
Total Pressurized Volume	880-3,500 ft^3 (25-100 m^3)
Average Power	3-5 kW
Pointing Capability	1 arc sec
Data Transmission	50 Mbs Digital, 5 MHz Analog/Video
Data Recording	30 Mbs Digital, 2.5 MHz Analog, 5.0 MHz Video
Mission Duration	7-30 days
Orbital Parameters	100-300 n. mi. (185-555 km) Altitude 28-104 degree Inclination

Other Support Available

View Ports	Airlocks	Manipulators
Extra Vehicular Activity	Booms	Controls
Displays	Film Vault	Computer
Equipment Racks	Thermal Control	

The progression of events making up a typical Spacelab mission would be essentially as follows. When the experimenter has determined that his system requires space testing and that it has reached the level of maturity needed to assure a reasonable degree of success, he would contact the Spacelab operational organization to obtain the data needed to integrate his experiment into the Spacelab. In the case of the experiment discussed previously, a logical plan would be to ship a Spacelab rack assembly to the experimenter's laboratory. The experimenter would then install his apparatus in the racks, which in turn would be assembled on the pallet, which will be available in modular lengths up to 15 meters. Figure VIII-11 illustrates this modularity and how these structures separate from both the Shuttle and Spacelab pressurized module. During testing of the system, any problems which resulted from the installation would be solved. The rack or rack and pallet assemblies would then be shipped intact to a central integration site, possibly at the launch site, where they would be installed in the laboratory module and, again, would be operationally verified.

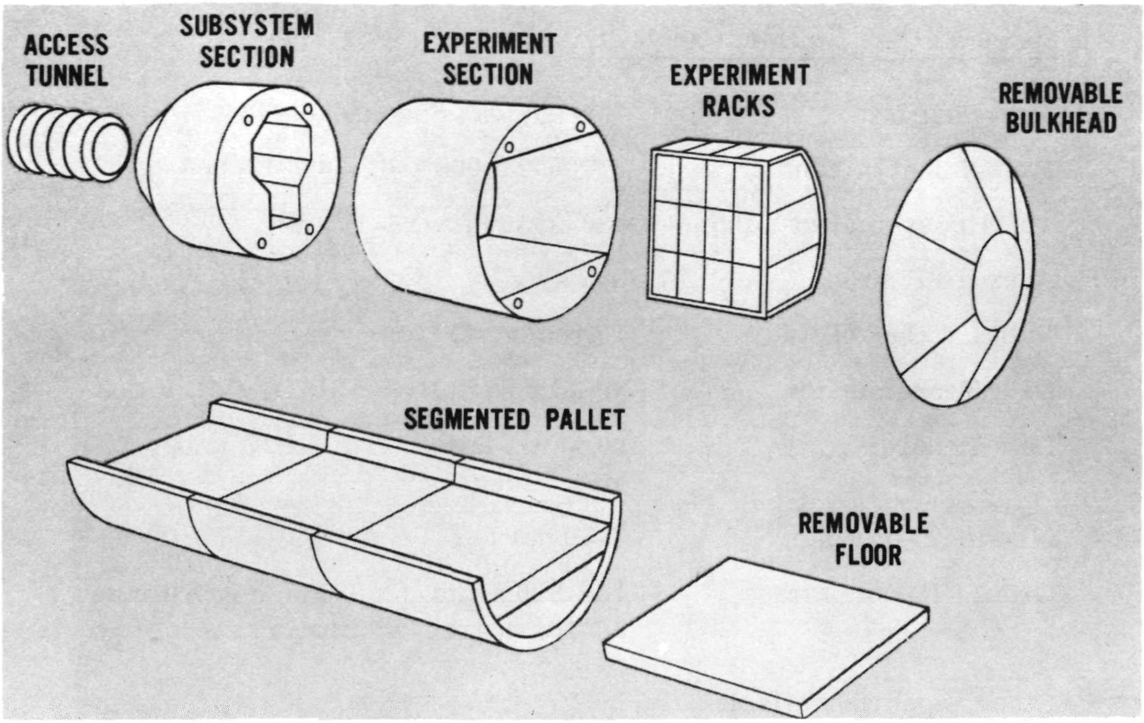

Figure VIII-11. Spacelab modularity.

At this point one of the most significant aspects of the Spacelab is introduced, namely, that with minimum training, now estimated at about 8 weeks, an experimenter would be able to accompany his experiment into orbit and make the observations and corrections needed to understand the phenomena being studied. The Shuttle Orbiter would provide for the housing and well-being of as many as four experimenters, as well as the three crewmen needed to operate the Shuttle itself.

When the module and pallet have been installed in the Shuttle, the experimenter would operate his equipment in orbit for a period of up to 30 days and return to Earth with the desired data. He will also have available a nearly continuous broad-band transmission capability to earth, allowing coexperimenters to examine the data also and advise him of alternate procedures which could enhance the results. When the orbital flight is completed, the apparatus could be returned to the experimenter's laboratory for use in subsequent laboratory or orbital experiments. Thus, the Spacelab and Shuttle now being designed will make space readily available to experimenters, extending to space the capability of ground laboratories.

Though still premature, present plans are to procure sufficient quantities of the various Spacelab elements from ESRO to satisfy anticipated user needs.

5. MAN'S ROLE IN SPACE

The ability of men to apply their knowledge, their skills, their powers of observation and their judgement directly in the performance of space operations is another resource that the Shuttle and Spacelab will make available to users on a routine basis, to be used wherever it is effective to do so. Because of past experience with manned operations in space, particularly with the recently completed Skylab missions, attention can be focussed on specific applications of man's living and working in space, rather than trying to treat the subject in broad and general terms.

The Skylab crews interacted with the experiments in almost every way and at every level that previous discussions of this subject have identified, ranging from scientific investigator to technician to repairman, from observer and interpreter to switch thrower and film changer.

a. Solar Astronomy. In the solar observations from Skylab, the crews directed the array of instruments to specific features on the solar disk to determine the types of activity present there. For the Sun, much of this activity changed so rapidly that frequently the selection of a specific area or event was completely based on the crew's observations in real time. For example, the crew's ability to perceive fluctuations in the extreme ultraviolet, as well as invisible wavelengths, was essential to getting the instruments properly configured for obtaining data on the early stages of flare buildup.

Other observations, such as active region studies, were scheduled by the principal investigators on the ground since active regions are relatively long lived. In either case, with less than perfect communication, the capability to use a man on board to be part of the feedback loop in doing the pointing greatly simplified the control situation. By contrast, it required a great deal of effort to do the pointing to catch the transit of Mercury across the sun during one of the Skylab unmanned periods. This was only partially successful, but, had the crew been on board it would have been trivially easy.

b. Earth Observations. Both Apollo and Skylab experience substantiated the point that a man's ability to recognize objects and patterns, to integrate his observations over a range of aspect and lighting angles, to reason and to make selective observations can bring another dimension to the area of Earth observations, extending beyond what is practical to do on an automatic, preprogrammed basis.

The crewman in space has an excellent vantage point from which to scan a large field of view and to select the significant features for study. Rapid discrimination allows maximum possible time to observe a feature by locating it early and by viewing it from horizon to horizon. Increased viewing time permits more thorough observation and description. In addition, it provides a better base for high-quality stereophotography and high resolution, multi-spectral imaging of selected sites.

Because many features change in appearance as the Sun angle and the viewing angle change, the crewmen were able to select optimum conditions under which to observe and to take data for a particular feature. Using the ability of the human eye to sense parameters such as color, texture, size, and shape, the men were able to detect temporal changes in a given area, as well as to detect regional differences in color, texture, and patterns and to compare different global areas. Such comparative data were often attainable even though viewing conditions varied between regions. The crewman's ability to mentally remove the effects of conditions such as haze, viewing angle, and illlmination is unique. Conditions such as haze and cirrus clouds, which may seriously degrade single photographs are not always such a serious hindrance to continuous observation from a moving space platform. The "picket fence" effect permits observations around and under cloud cover.

In manmade geometric field patterns, colors, sizes, and shapes can be detected and classified through as much as 75 percent cloud cover. However, in regions where land-use patterns are less geometric, such as in the arid lands of Mali, such recognition and classification is much more difficult. Perception is also difficult in areas of low contrast, such as older cities constructed of local building materials. Cities constructed of materials foreign to the area are more easily discerned. Additional training may enable better recognition in the lower contrast areas as well.

Dynamic features such as ice and snow cover are also easily observed. For example, during the third Skylab mission, significant changes in ice structure in the Gulf of St. Lawrence were noted on consecutive revolutions (about 90 minutes apart). Daily changes in snow cover are observable, as are snow-melting patterns. The Skylab crews demonstrated that a trained observer can detect color changes in a crop growth cycle and can probably establish optimum times to obtain additional remote sensor information.

Another example occurred with the sunglint phenomenon. Sunglint is a rapidly changing phenomenon that is valuable for viewing the surface texture of water. Many large-scale surface features of the oceans were seen for the first

time in sunglint; these had not been anticipated before the mission. To take advantage of this phenomenon, the crewman had to recognize and identify the feature of interest in the sunglint pattern. He had approximately 5 seconds to observe a feature, decide on the appropriate observational technique, and perform it for the unpredicted feature. Although the occurrence of sunglint is predictable, the features that will be visible in the sunglint cannot be predicted. For example, the outer edges of certain features in sunglint are more useful than the central area. A crewman is able to determine the optimum time for the photograph to take full advantage of the phenomenon.

For the development of new sensors or observational modes, manned operation can greatly increase the flexibility of Earth observations from space platforms. When new observational information indicates the desirability of a change in procedures, or instrument settings, the required changes can be incorporated into the plan and subsequent modifications can be made, all within the same mission. Otherwise, each change could represent a major program iteration and a new mission.

In future Earth observations missions, such a combination of man and a semi-automated instrument package could greatly enhance scientific data return. The crewman contributes the unique human attributes of judgment, selectivity, observations, and flexibility; the instruments contribute a high resolution multispectral capability and furnish a permanent record of the data gathered.

c. Space Processing. For experiments that are not primarily observational but are active, in the sense that data are recorded as a function of changing experimental conditions, a man can play an important role in monitoring and changing the experimental conditions. This does not mean that he should be placed in the control loop to keep temperature constant by adjusting the current flow; that sort of control is obviously best done automatically, but such judgemental functions as the optimum focusing of an electron beam can be done easily by an observer, as was done on Skylab. Further, if a man were on board to examine the results of an experimental run, even in a precursory way, he would be then in a position to modify the planned procedures for a subsequent run. In the Skylab materials processing experiments, analyses of the results of the second mission were used to modify procedures and time/temperature profiles used on the third mission. With the necessary equipment on board, a qualified operator could have made such changes in flight and performed further runs during the same mission.

The key to the effective utilization of man in these roles is the availability of the right data and the design of the experiment. If a man is to play a significant role in the control of an experiment he must be given the data and displays necessary to make decisions and the controls to carry them out. Determining whether the decisions are made on the ground or on board is a function of the feasibility of sending sufficient data to the ground and the time frame within which a response is needed.

d. Reconfiguration, Construction, and Repairs. Less sophisticated but still very important areas where a man can play a significant role are in the reconfiguration of equipment and the repair or maintenance of equipment. Although there may be ways of automating functions such as the exchange of instruments in a Scientific Airlock, use of cameras with a variety of film types, and exchange of sample disks in a furnace chamber for materials processing experiments, a man's performing these tasks can greatly simplify the design of experiment equipment. It also has the advantage of allowing apparatus to be launched in an optimum configuration for sustaining launch loads and then to be assumbled in orbit for operation without complicated mechanisms.

Almost any assembly or repair task that would reasonably be expected to be performed on earth by one or two men can be done in zero g. There is a requirement for body stabilization, preferably by providing some sort of restraint for both feet; this eliminates the need for so-called reactionless tools.

Extravehicular activity (EVA) on Skylab demonstrated that, given the proper tools and body restraints, a man can perform many useful functions. These ranged from delicate operations such as using a brush to remove a light scattering bit of fibrous material from the occulting disk of the solar coronagraph to tasks involving prolonged and substantial physical exertion, as in the case of freeing and erecting the solar panel damaged during the Skylab launch. Skylab EVA's typically ranged from $1\frac{1}{2}$ to 7 hours long. None had to be terminated before completion of the assigned tasks, and in many cases, the jobs were completed ahead of schedule.

With regard to handling of components outside the spacecraft, it should be kept in mind that visibility out of a pressurized suit is restricted, so it is difficult to keep track of the ends of long objects. Therefore, component length should be no more than about 6 or 7 feet. Longer items can be handled, of course, if the normal mode of handling is by "feeding" directly away from the worker. An example is the sunshade erected by the second Skylab crew. Two poles, each 55 feet long, were assembled by the EVA crewman, but they were made up of 5-foot lengths, so both ends could be kept in view during assembly.

e. Summary. The Skylab missions showed that men can live in space for extended periods, actively enjoying the experience of weightlessness, and that they can work effectively and productively, performing much the same kinds of functions that they could in a ground-based or airborne laboratory. Planning for the Shuttle and the Spacelab can take full advantage of this wherever the use of manned operations can contribute to the goals of the Applications program.

6. APPLICABLE DOCUMENTS

a. Man's Role in Space

Garriott, O. K.: Man's Role in Space Research in Skylab (in preparation).

Man-System Design Criteria for Manned Orbiting Payloads. MSFC-STD-512 (in preparation).

Parker, R. A. R.: The Use of Man to Repair and Modify Equipment in Orbit.

Short, N. M., and Lowman, P. D., Jr.: Earth Observations from Space: Outlook for the Geological Sciences. GSFC X-650-73-316.

Skylab 4 Visual Observations Project Report (in preparation).

Weitz, P. J.: The Role of Man in Conducting Earth Resources Observations from Space. Aeronautics and Astronautics.

b. Space Shuttle

Space Shuttle System Payload Accommodations; Space Shuttle Level II Program Definition and Requirements. Vol. XIV. Johnson Space Center.

c. Space Tug

Baseline Space Tug Definition Document. MSFC (in preparation).

Payload Utilization of Tug Study, Final Report; Executive Summary. NASA Contract No. NAS8-29743 (in preparation).

Tug Operations and Payload Support Study, Final Report; Vol. I, Executive Summary. Rockwell Report No. SD 73-SA-0006-1, NASA Contract No. NAS8-28876, Mar. 5, 1973.

d. Spacelab

Spacelab Programme Requirements, Level I. ESRO-SL-74-1, NASA-MF-74-1, Mar. 5, 1974.

Spacelab System Requirements, Level II. ESTEC SLP/2100, MSFC SO-74-127, Mar. 1, 1974.

Spacelab Users Guide.

e. Payload Characteristics and Effects

Lockheed Missiles and Space Company: Payload Effects Analysis Study, June 1971.

Aerospace Corporation: Payload Characteristics. Report No. ATR-72 (7231-1).

f. Payload Cost Effects

Aerospace Report ATR-74 (7334)-1.

Grumman Study of OAO. July 1972.

LMSC Payload Effects Study. LMSC-A990556, June 1971.

On-Orbit Servicing Study, Bell Aerospace Co., January 1974; COMSAT, January 1974; Martin-Marietta, December 1973.

RCA ITOS/Space Shuttle Study. AEDR-3689.

TRW Study of DSP Spacecraft, June 1973.

CHAPTER IX. OVERVIEW OF ECONOMIC ANALYSES

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER IX. OVERVIEW OF ECONOMIC ANALYSES

1. INTRODUCTION

In the early years of the Space Program, the thrust of the national effort was directed first toward the launching of an orbital spacecraft to meet the challenge of the U.S.S.R.'s Sputnik and later toward the national commitment to land a man on the moon in the decade of the 1960's. It was an era of intense international competition for supremacy in space and technology and of recognition of the need for increased scientific understanding of our solar system and the universe. Space exploration missions, whether science or applications oriented, when proposed to the Bureau of Budget (as it was then called) and Congress, were endorsed primarily on the basis of the contributions of these missions to scientific and technological supremacy.

In that early period, space was a new national frontier which challenged both the imagination and the resources of the nation. In that climate, the areas of science and technology and of research and development received strong support at the highest national levels. While costs of space missions received serious consideration, there was little or no mention of cost benefits, cost effectiveness, or economic analysis in conjunction with discussions of these early missions. However, in the early years of the sixties, NASA on its own initiative undertook some economic analysis studies and cooperated with other Federal agencies in co-sponsoring other, more extensive studies which touched upon the socio-economic and political implications of specific pioneering applications areas. One of the applications areas to receive early attention was communication satellite systems.

A study conducted by the Rand Corporation in 1961 focused primarily on the costs of communications satellite systems. This study, Economic Aspects of Communications Satellites, not only investigated the cost of such systems but also the prospects of using the vast increase in transoceanic communications capacity. No attempt was made in these early studies to price out benefits and to derive cost-benefit ratios. Rand Corporation produced another report in February 1963 in the public interest; it was entitled Communications Satellites: Technology, Economics, and System Choices. Drawing extensively on previous research studies undertaken by Rand for NASA, this study considered the possible system choices implied by the U.S. policy to establish a commercial communications satellite system and its extension to provide global coverage. The study not only explored system costs but also estimated revenues. NASA-sponsored research studies by the Rand Corporation in the early 1960's also

included Overseas Telecommunications Traffic and Commodity Trade, a statistical analysis of the relationship between these two areas; and The Market for Overseas Telecommunications in 1970, an exploration into the potential market for overseas telecommunication services in 1970, both in terms of size and configuration.

An Arthur D. Little Co. study in 1965 was entitled World Telecommunications. This study noted the great potential impact of satellite communications and data communication services and the major developments in world telecommunications at that time. A multi-client follow-on survey and study on world telecommunications, which essentially updated the earlier one, was completed in 1971. This later report provided a description and measurement, for the period 1970-1980, of the world's telecommunications markets and assessed the state-of-the-art of telecommunications technology and its future. This later study treated the world market by continents and delved into four major areas, namely, economic and political setting; organization and regulations of telecommunications; telecommunications services, tariffs, and traffic; and facilities and equipment markets. It was primarily a global market research study rather than cost-benefits study, although much of the data developed could be used in economic analyses.

Recently, the major thrust of industry into the domestic and international satellite communiccations field has permitted a curtailment in the NASA effort. The current emphasis in NASA is in consultative service to public sector users and in the development of technology to meet longer range national needs. The near-term activities are being left to the initiative of private enterprise. Thus, economic analysis in communications satellite systems has experienced a corresponding de-emphasis in NASA.

In meteorology, another of the older applications disciplines, numerous economic analyses were conducted, resulting in a number of statements formulated by knowledgeable federal organizations on weather-related losses in terms of dollars. These much quoted figures were in terms of total losses due to hurricanes, tornadoes, etc., with little or no detailed backup data. More recent studies have addressed the detail and will be reviewed later.

Cost-benefit and cost-effectiveness studies and economic analyses assumed importance in the 1970's with a reappraisal by the public of national priorities and national problems such as ecology, the environment, and critical resource needs. With the attainment of the major space goal of the 1960's, i.e., the landing of man on the moon, the support for the Space Program lost some of its early glamour and momentum. As a consequence, a growing need developed to consider and evaluate the economic and social implications of space developments.

An early economic study in earth resources applications performed for NASA by the Planning Research Corporation (PRC) in 1966 was entitled A Study of Economic Benefits and Implications of Space Station Operations. This study was based upon a hypothetical Earth Resources Technology Satellite (ERTS) and explored the applications of remote sensing techniques to rice crop production, wheat rust control, and water power generation from stream flow forecasts. A final report was produced in 1967.

It was early in 1968 that the Bureau of the Budget directed NASA to conduct a follow-on study wherein cost-benefit ratios were to be developed for water management, wheat crop management, and wheat rust control. This substantive effort by PRC, entitled A Systems Analysis of Applications of Earth Orbital Technology to Selected Cases in Water Management and Agriculture, resulted in a final report published in November 1969. This study was done under the general guidance of the multi-agency coordinating body, the Earth Resources Survey Program Review Committee (ERSPRC) through a Benefits Studies Subcommittee.

In the 1967-1968 NAS-NAE Study on Useful Applications of Earth-Oriented Satellites, cost-benefit relationships were studied. A number of consultant economists and economist-engineers analyzed the systems postulated by the various applications discipline panels, estimated the costs of development and operations, and appraised foreseeable benefits. The concensus of this group of specialists was, ". . . these new and challenging fields of satellite and sensor technology are advancing so rapidly that caution must accompany any attempts at economic appraisal. The conventional cost-benefit analysis approach is not suitable for judging technologies in the fluid, formative state. Instead, in evaluating the different space applications, we are advised to use guides that have been widely adopted by business for planning and developing new products, processes and services."[1]

These guides, representing a typical industrial concept, were comprised of four steps over a 5 to 10 year period and included:

a. Basic and exploratory research (least costly).

b. Development: early design, limited testing.

c. Pilot plant: market-testing programs.

d. Operation: design, construction, and operations of commercial plant.

---

1. Report of the Central Review Committee, 1967-1968 NAS-NAE Summer Study, pp. 10-11.

Using this approach, it was stated that prior to making the greatest cost commitment, sufficient data are available to the decisionmaker to assess relevant costs and benefits.

This early study could be considered as introductory and outlined two separate approaches. The first approach was to use industry guides comprising four steps as noted above. As a second approach, the study recommended "a benefit-cost analysis using a disciplined, methodological approach to systems analysis." Attention was focused primarily on the cost of various systems and not on the benefits. In the multi-discipline program area of earth resources, for example, there was only limited experience in the techniques of how the early data from manned spacecraft and remote sensing aircraft could be used and less information on how these data could be applied.

The launching of the first Earth Resources Technology Satellite (ERTS-1) on July 23, 1972, gave new impetus to economic analysis, cost benefit, and cost effectiveness studies. With the Earth Resources Survey Program in the flight test phase, the matter of a decision on an operational system became much more pressing. Further, with several hundred domestic and foreign investigators exploring how ERTS imagery could be used, the economists have more data and information upon which they can base their analyses. The input information for models becomes more realistic with time, since it is being derived from significant results and facts evolving from ERTS investigations rather than upon conjecture.

A study effort by Dynatrend Corporation entitled Evaluation of Benefits and Systems Features of Earth Resources Survey Satellite Systems, dated August 31, 1973, was aimed at a re-examination of earlier benefits estimated by the Interplan Corporation study of March 1971, but transposed to the later time by surveying many of the ERTS-1 principal investigators to get an updating of these benefits based upon their most recent and significant findings. These same investigators were also queried regarding what system modifications to ERTS-1 they would recommend in order to gain increased benefits.

There is a standing requirement for economic analyses today in the Applications Program. Both the Office of Management and Budget (OMB) and Congress have expressed an interest in economic analyses. The OMB is imposing requirements upon NASA to conduct in-depth cost-benefit and cost-effectiveness studies in new discipline areas so that adequate information is available before the nation commits itself to costly, large scale operational space systems.

Perhaps the most significant on-going study effort and the one which has multi-agency support and direction today is the Department of Interior's study being conducted jointly by EarthSat Corporation and Booz Allen Applied Research Corporation which has as its objective the provision of a basis for future government investment decisions regarding earth resources survey satellite systems. Its approach is to evaluate and compare U.S. benefits from (1) an operation ERTS-like system, (2) a high-altitude aircraft system, and (3) existing systems using case study approaches in a few specific applications areas.

Since recent, new applications areas address critical national needs, detailed economic analyses are almost imperative. For example, NASA's efforts in pollution monitoring and detection raise many socio-economic and political questions. These same questions apply to NASA's possible role in solar energy heating and cooling and to self-contained utility systems, as mentioned above. With regard to SEASAT, a new program designed to provide information on global ocean dynamics and physical properties to a broad range of potential users both in the public and private sectors, the OMB has already requested that NASA conduct a detailed cost-benefit analysis. Economic analyses of any major undertaking or program assumes greater inportance with time, the overall decrease in natural resources, and the increase in population and attendant problems.

There are a number of questions on economic analyses and cost-benefit studies which need to be addressed. They include:

a. Are the potential benefits of anticipated successful research and development (R&D) programs of sufficient magnitude to warrant the initial investment? While these benefits, both real and potential, may exist, they need to be documented in a credible manner.

b. If large potential benefits exist in some applications areas, why should the Federal Government finance the R&D effort with public funds? Shouldn't this responsibility rest with industry? The answer to this latter question may differ in each of the specific applications areas.

c. Does there currently exist enough economic confidence (evidence) in each application area or program to commit the nation to an operational system investment? As a corollary to this question, what has been the experience in earlier operational space programs which may be applicable? What is the future promise in these areas and in the new areas?

d. What is the role of civilian R&D, both government and private sector, in the economy, and to what extent has space R&D contributed to these economic benefits?

2. SUMMARY REVIEW OF SELECTED STUDIES

Following are summary reviews of a selected number of economic studies, both completed and on-going, on what has been done, what is currently under way, and what is planned in economic analysis and in cost-benefit and cost-effectiveness studies. Greater detail may be found in the Appendices volume.

a. Past Studies and Their Respective Applications Areas

(1) 1967-1968 NAS-NAE Summer Study on the Useful Applications of Earth-Oriented Satellites. The summer study considered all applications disciplines existing at the time and a few advanced applications disciplines; however, the economic analysis effort was rather limited and an overall economic assessment was never published.

(2) Interplan Corp. Study — Review and Appraisal: Cost Benefit Analyses of Earth Resources Survey Satellite Systems, March 1971. This study is useful as a summary and integration of 10 previous economic benefit studies in Earth Resources Survey Systems and it covers the full range of specific applications. A list of the 10 studies is given in Table IX-1.

(3) Dynatrend Corp. Study — Evaluation of Benefits and Systems Features of Earth Resources Satellite, August 31, 1973. Using the Interplan Study as a base, this study reassessed the benefits of 85 specific applications based upon ERTS-1 results. In addition, ERTS-1 Principal Investigators were contacted to determine what systems modifications or improvements should be made to ERTS-1 to achieve the benefits highlighted in the Interplan Study.

(4) Mathematica Inc. Study — Cost Benefit Analysis for ERTS Experiments, Vol. I, June 30, 1973. This study provides an explanation of the techniques and terms of cost-benefits analysis for applications to ERTS experiments; it would be particularly useful to newcomers to the space program.

TABLE IX-1. DOCUMENTS REVIEWED AND APPRAISED BY INTERPLAN

Document No.	Originating Organization, Report Identification, and Publication Date	Report Title	Immediate Sponsor
1	Stanford Research Institute, Project M-5465, September 1965	Priority Analysis of Manned Orbital Research Applications	Douglas Aircraft Co., MSSD
2	International Business Machines, Federal Systems Division, NASw-1215, February 1966	Orbiting Research Laboratories (ORL) Experiment Program	NASA
3	Cornell University, The Center for Aerial Photographic Studies, December 1967	Potential Benefits to be Derived from Applications of Remote Sensing of Agricultural, Forest, and Range Resources	NASA/USDA
4	Westinghouse, Defense and Space Center, 7145A2, Dec. 1967 (Final Summary Report February 1968)	EROS Applications Benefit Analysis	USDI
5	Planning Research Corporation, PRC R-1218, January 1968	A Study of the Economic Benefits and Implications of Space Station Operations	NASA
6	General Electric Co., Missile and Space Division, March 1968	Final Report on the Space/ Oceanographic Study	National Council on Marine Resources and Engineering Development
7	Mathematica, GLM, September 1968	Cost Benefit Study of the Earth Resources Observation Satellite System: Grazing Land Management	RCA, AED
8	Mathematica, ECM, June 1969	Cost Benefit Study of the Earth Resources Observation Satellite System: Estuarine and Coastal Management	RCA, AED
9	Planning Research Corporation, PRC R-1224, November 1969	A Systems Analysis of Applications of Earth Orbital Space Technology to Selected Cases in Water Management and Agriculture	NASA/Bureau of the Budget
10	Summer Study on Space Applications, National Academy of Sciences, National Research Council, January 1969	Useful Applications of Earth-Oriented Satellites	NASA

(5) Mathematica Inc. Study — An Example of the Potential Benefits of ERTS Imagery for Environmental Control, June 30, 1973. This cost study applied ERTS-1 data and the techniques presented in the previous Mathematica Study, noted above, to surface mining control in the Eastern Kentucky coal mining region.

(6) Mathematica Inc. Study — An Econometric Model of the U.S. Telecommunications Industry, August 1973. This study formulated an econometric model of the U.S. Telecommunications Industry which took into account (a) the various interrelationships among the various components of supply and demand (i.e., demand and revenue, supply and cost, and gross investment and new employment) and (b) the effect of research and development in technological progress.

(7) University of Wisconsin — Studies of the Social, Economic and Political Impact Resulting from Recent Advances in Satellite Meteorology, June 1971 - August 1972. These studies explore and evaluate the impact of the meteorological satellite and of the data derived from it on various user groups.

(8) ECON, Inc. — The Economic Value of ERTS-B, January 18, 1974. This study addressed the value and cost-effectiveness of the ERTS-B program, first, taken by itself and, second, as a forerunner to the development of an early operational system. It also explored the cost-effectiveness of an operational ERS system in comparison with other data collection systems, such as one comprised of high-altitude aircraft for a few selected applications.

b. Current Studies

(1) ECON, Inc. — Economic Analysis of the Role of an Earth Resources Satellite (ERTS) System in the Establishment of a Nationwide Land Use Information Data Bank. This is an economic analysis of alternative methods, including ERTS, for the acquisition of land use information to be used in the development of nationwide land use planning information systems.

(2) O.R.I. — An Economic and Social Benefit Investigation of Weather-Related Programs. Existing literature and specialized weather forecasts (furnished by both the public and private sectors) will be studied to determine weather-related, socio-economic benefit areas. A second phase to develop a plan for an in-depth study of these weather-related, socio-economic benefit areas may be considered.

(3) EARTHSAT CORP/Booz Allen Study — Evaluation of Economic, Environmental and Social Costs and Benefits of Future Earth Resources Survey Satellite Systems. To evaluate and compare U.S. benefits from (1) an operational ERTS-like system, (2) a high-altitude aircraft system and (3) existing systems using case study approaches in a few specific applications areas. This is by far the largest and most comprehensive cost-benefit study effort undertaken in Earth Resources and is a coordinated, multi-agency activity.

(4) Task Force on Economics of Remote Sensing. This special group comprised of NASA staff members and representatives from the private sector is to provide economic justification for the NASA Earth Resources Survey Program and to develop NASA capability to establish economic benefits.

(5) ECON Inc. — SEASAT Economic Assessment. This is a study to estimate the net value of the SEASAT program and to put together the mutually supporting relationships to promote an operational system in direct assistance to NASA and potential users.

3. FUTURE ACTIVITIES

What Needs to be Done. A leading economist who has worked on earth-oriented applications over a considerable period of time has developed a set of questions which hopefully will generate answers and the data relevant to in-depth economics analyses in space applications. These questions relate to several broad areas, including (1) the objectives of new or existing space applications programs or projects; (2) the alternative to a space-oriented system; (3) the alternatives within a space-oriented system; (4) estimated costs related to the total life cycle of systems ranging from initial research to the ultimate operational system; (5) benefits over various periods of time, i.e., 5 years, 15 years, etc; (6) relevant studies; and (7) institutional and organizational aspects.

NASA-sponsored studies in the economics of space applications has been wide-ranging but made difficult, and sometimes inconclusive, by a lack of internal-to-NASA professional capabilities in this field. The work has also been constrained by the fact, pointed up in the 1967, 68 Summer Study that "...conventional cost-benefit analysis approach is not suitable for judging technologies in the fluid, formative state."

TABLE IX-2. COMPARISON OF DOCUMENTS BY NUMBER OF BENEFIT ESTIMATES AND SCOPE

Document No.	Report Identification	Number of Benefit Estimates Made for Applications in the Earth Resources Disciplines						Scope
		Agriculture	Geology	Geography	Hydrology	Ocean Sciences	Multidiscipline	
1	SRI M-5465	3	1	1	1	4	1	U.S. and world benefits from a Manned Orbital Research Laboratory. Not a system study.
2	IBM NASw-1215	12	3	2	5	6	–	U.S. and world benefits from a Manned Orbital Research Laboratory. System orientation, but not a system study.
3	Cornell	126	–	–	–	–	–	U.S. and world benefits to agriculture, forestry, and range management. Not related specifically to satellite observation. Not a system study.
4	Westinghouse	9	11	4	4		1	Benefits estimated in USDI areas of interest as a function of resolution and frequency of observation. Not a system study. Unmanned.
5	PRC R-1218	6	2	3	4	2	5	System studies on cases pertaining to rice production, wheat rust control, malaria control, hydroelectric power generation, fish production. Unmanned.
6	GE	–	–	–	–	3	–	Detailed system study on fishing and shipping applications. Unmanned.
7	Mathematica GLM	3	–	–	–	–	–	Cost-benefit analysis of a grazing land management application. Not a system study. Unmanned.
8	Mathematica ECM	–	–	–	1	–	–	Cost-benefit study of estuarine and coastal management applications. Not a system study. Unmanned.
9	PRC R-1224	11	–	–	4	–	–	Detailed system studies on cases in agriculture and hydrology – an extension, in-depth, of the PRC R-1218 study. Unmanned.
10	NAS Summer Study	6	1	–	–	1	–	An assemblage of expert opinion on the usefulness of ERS observations in all major disciplines. System cost estimates for separate disciplines and common-use systems. Unmanned.

NASA is developing in-house professional competence in this field, both by retraining of present personnel and by bringing into the Headquarters and field organizations economists who can interact with the users and with the NASA technologists to develop greater understanding of the methodologies and applicability of cost-benefit analysis in its programs. Funding of studies by NASA and jointly with other agencies and users will continue.

CHAPTER X. PROGRAM RESOURCES

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

CHAPTER X. PROGRAM RESOURCES

1. INTRODUCTION

The following tables and charts are intended to provide a concise overview of the approved and planned spaceflight missions for the period 1974 to 1991. They are drawn from a mission model that NASA has developed to assist in planning for the utilization of the space transportation system and the Spacelab (previously called Sortie Lab). The resources (funding) charts are for the 1964 to 1980 period; the 1964 to 1974 (fiscal years) are actual; 1980 represents the planning horizon of the NASA budgeting process.

Except for the approved missions, marked with a circle, these data are for planning purposes only.

2. FLIGHT MISSION SUMMARIES

Table X-1. Earth Observations Program, 1973 to 1991

Table X-2. Earth and Ocean Physics Applications Program, 1973 to 1991

Table X-3. Communications and Navigation Program, 1973 to 1991

Table X-4. Space Processing Program, 1973 to 1991.

3. RESOURCES SUMMARY

Figures X-1 and X-2 summarize the funding history in the NASA Applications Program for the period 1964 to 1974, and project the funding into 1980 for both the approved program (Fig. X-1) and for a total program based on NASA obtaining Presidential and Congressional approval of the new programs and projects it would introduce in the 1975 to 1980 period.

The funding levels represent NASA expenditures to buy equipment and services in direct support of the programs. They do not include space transportation system or Spacelab development on any prorated basis nor do they include any tracking and data acquisition costs since those services are provided through separate funding on an Agency-wide basis.

Also the funds are the direct research and development expenditures in Applications and thus, do not include reimbursable expenditures; i.e., funds NASA receives from another agency to carry out work for that agency. An example of a reimburse expenditure is that money NASA receives from NOAA for the manufacture, test, and launch of operational meteorological satellites.

Finally, these expenditures do not include funds for those NASA civil service employees who work on the program and only partly for the institutional support (facilities, computers, etc.) provided to the program. NASA has, Agency-wide, approximately 1600 man-years of in-house effort committed to the Applications Program in 1974, spread over eight of the nine NASA field centers.

TABLE X-1. EARTH OBSERVATIONS PROGRAM

Payload Code	Payload	CY	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	Total
	Automated Spacecraft																					
EO-1	Earth Resources Tech. Sat.					1																1
EO-2	NIMBUS			1			1															2
EO-3	Earth Observatory Sat.							1	1	1	1	1	1	1	2	1	1	1	1	1	1	15
EO-4	Syn. Earth Obs. Sat.										1		1		1		2		2		2	9
EO-5	Special Purpose Sat.					1	1	1	2	2	2	1	1	1	1	1	1	1	1	1	1	19
EO-6	TIROS						1					1					1					3
EO-7	Syn. Meteorological Sat.		1	1				1									1					4
	Total Autom.		1	2		2	3	3	3	3	4	3	3	2	4	2	6	2	4	2	4	53
	Sortie Payloads																					
EO-8	(Weather Simulation Lab., Sensor R&D)									2	2	2	2	2	2	2	2	2	2	2	2	24

Note: ◯ Approved and Ongoing

TABLE X-1. (Continued)

PAYLOAD CODE	PAYLOAD	PAYLOAD OBJECTIVES AND DESCRIPTIONS		
		WEIGHT kg (lb)	DIMENSIONS (Length/Diameter) m (ft)	DESTINATION (Incl./Apo./Per.) km (n.mi.)
	Automated Spacecraft			
EO-1	Earth Resources Technology Satellite (ERTS)	Will sense heat radiated by surface features in order to locate, map, and measure pollution in lakes, bays, and estuaries and to provide data on suitability of soil for cultivation and resources for exploitation. Investigations will be conducted using multispectral scanner, return beam vidicon camera, and data collection system.		
		900 (2000)	3.7/1.5 (12/5)	90°/912 (490) Circular
EO-2	NIMBUS	Will test sensors designed to extend satellite measurements of the atmosphere's vertical temperature and moisture content to cloud covered areas and to higher altitudes and make atmospheric composition measurements for establishing global baseline data for polluting constituents of the air. Instrumentation will include assortment of radiometers, spectrometers, and imagers.		
		900 (2000)	3.7/1.5 (12/5)	90°/1100 (600) Circular
EO-3	Earth Observatory Sat. (EOS)	Will perform environmental quality, meteorological, oceanographic, and Earth resources surveying by advance remote sensing techniques. Will carry advanced instrumentation such as the thematic mapper and next generation multispectral scanner. High resolution pointable imager, radar, microwave radiometer.		
		2950 (6500)	11/2.7 (36/9)	99°/914 (494) Circular

TABLE X-1. (Continued)

PAYLOAD CODE	PAYLOAD	PAYLOAD OBJECTIVES AND DESCRIPTIONS		
		WEIGHT kg (lb)	DIMENSIONS (Length/Diameter) m (ft)	DESTINATION (Incl./Apo./Per.) km (n.mi.)
EO-4	Synchronous Earth Observatory Sat. (SEOS)	Will investigate and develop remote sensing techniques for measurement of the Earth's transient environmental phenomena from synchronous altitude. SEOS will utilize spacecraft base of EOS and carry multidisciplinary instrument complement — radiometers and multispectral scanners.		
		2300 (5000)	3.7/2.4 (12/8)	0°/Synchronous Orbit
EO-5	Special Purpose Satellite	Will test experimental application of research and technology developments in spacecraft and sensor subsystems. Will provide quick reaction to objectives identified by application disciplines and enable the conducting of special purpose missions dedicated to developing advanced sensors and instrumentation. In geosynchronous orbits, much of the emphasis will be devoted to evaluating various atmospheric sounding techniques.		
		230 (500)	2.1/1 (7/3)	0°-90°/Low Earth to Sync. Orbit
EO-6	TIROS	Will determine atmospheric pressure and density, vertical temperature and wind profiles, and sea-state, convection, and surface temperature using advanced sensing and observing techniques.		
		1977: 337 (742)	1.9/1 (6.2/3.3)	102°/1460 (790) Circular
		1977 On: 635 (1400)	3.7/2.4 (12/8)	102°/1460 (790) Circular

TABLE X-1. (Concluded)

PAYLOAD CODE	PAYLOAD	PAYLOAD OBJECTIVES AND DESCRIPTIONS		
		WEIGHT kg (lb)	DIMENSIONS (Length/Diameter) m (ft)	DESTINATION (Incl./Apo./Per.) km (n.mi.)
EO-7	Synchronous Meteorological Satellite	Will be a prototype operational geostationary meteorological satellite based on proven technology. Will observe major storms and atmospheric parameters and collect data from fixed ground platforms. Will utilize visible and infrared spin scan radiometer to provide day and night weather pictures.		
		250 (550)	3.1/1.9 (10.3/6.3)	0° /Synchronous Orbit
	Sortie Payloads			
EO-8	(Weather Simulation Lab., Sensor R&D)	Will perform experiments on the dynamics of meteorological phenomena and will simulate conditions associated with cloud physics. Will conduct specially dedicated missions for the remote sensing and study of Earth Resources and the environment. Will perform sensor development for all Earth observations disciplines. Will verify sensor measurement concepts. Note: Earth Observations, Earth and Ocean Physics, and Communications and Navigation Sortie payloads flown together.		
		11 300-12 200 (25 000-27 000) (Includes Expendables)	18.3/4.3 (60/14)	28.5° -90° /Low Earth Orbit

TABLE X-2. EARTH AND OCEAN PHYSICS APPLICATIONS PROGRAM

Payload Code	Payload	CY	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	Total
	Automated Spacecraft																					
EOP-1	Geodetic Earth Orbiting Sat.			1																		1
EOP-2	Laser Geodynamic Sat.					1																1
EOP-3	SEASAT						1					1										2
EOP-4	GEOPAUSE								1			1										2
EOP-5	Grav. Gradiometer									1												1
EOP-6	Mini-Laser Geodynamic Sat.									1					1							2
EOP-7	GRAVSAT								1													1
EOP-8	Vector Magnetometer Sat.										3					3				3		9
EOP-9	Magnetic Monitor Sat.										1					1				1		3
	Total Autom.			1		1	1		2	2	4	2			1	4				4		22
	Sortie Payloads																					
EOP-10	(Earth and Ocean Dynamics Experiments)									2	2	2	2	2	2	2	2	2	2	2	2	24

Notes:

○ Approved and Ongoing

TABLE X-2. (Continued)

PAYLOAD CODE	PAYLOAD	PAYLOAD OBJECTIVES AND DESCRIPTIONS: WEIGHT kg (lb)	DIMENSIONS (Length/Diameter) m (ft)	DESTINATION (Incl./Apo./Per.) km (n.mi.)
	<u>Automated Spacecraft</u>			
EOP-1	Geodetic Earth Orbiting Sat. (GEOS)	Will demonstrate the feasibility of measuring ocean surface topography by a satellite-to-ocean altimeter; will determine the feasibility of measuring deflection of the vertical and wave height; and will investigate solid Earth dynamics phenomena and refine orbit determination and gravity models.		
		270 (600)	1.3/1.2 (4.1/3.9)	115°/840 (460) Circular
EOP-2	Laser Geodynamic Sat. (LAGEOS)	Will make possible maximum accuracy range measurement for both geometric and orbital mode determinations of positions on the Earth which will permit the determination of plate tectonic regional fault motions, polar motion, and rotational variation. Will utilize very dense satellite equipped with laser retroreflectors to perform first laser range measurements not degraded by errors originating in the target satellite.		
		680 (1500)	0.6/0.6 (2/2) Sphere	90°/3700 (2000) Circular
EOP-3	SEASAT-A	Will demonstrate global-scale monitoring and reporting of a wide range of physical ocean phenomena, including sea-state, the location and transport of currents, global circulation patterns, ocean tides, wind stress, and geoid undulations. Instrumentation will include imaging IR radiometer, microwave scatterometer, etc.		
		1000 (2200)	4.6/4 (15/13)	90°/600 (325) Circular

TABLE X-2. (Continued)

PAYLOAD CODE	PAYLOAD	PAYLOAD OBJECTIVES AND DESCRIPTIONS		
		WEIGHT kg (lb)	DIMENSIONS (Length/Diameter) m (ft)	DESTINATION (Incl./Apo./Per.) km (n.mi.)
	SEASAT-B (Concluded)	Will monitor and report on a global basis ocean surface phenomena such as seastate geoid undulations, wind stress on surface water, location and extent of boundary currents and other sea-surface topography. Will be demonstration of real-time global monitoring of ocean dynamics conditions and near-real-time analysis and dissemination of SEASAT-B data to users.		
		1000 (2200)	4.6/4 (15/13)	90°/600 (325) Circular
EOP-4	GEOPAUSE	Will establish a Space Reference Network System consisting of a pair of GEOPAUSE spacecraft for determination of the orbital altitudes of Ocean Dynamics Monitoring Spacecraft in the decimeter range, simultaneous monitoring of polar motion and Earth rotation variations, detailed determination of crustal motions in three dimensions for tracing both the global patterns of tectonic plate dynamics and the local behavior near fault zones. Will utilize accelerometers as part of a closed loop drag compensated system.		
		1170 (2580)	2.5/2 (8.2/6.5)	90°/30 000 (16 200) Circular
EOP-5	Gravity Gradiometer	Will utilize gravity gradiometer to obtain an improved map of the Earth's entire gravity field. The horizontal resolution of satellite-determined gravity models currently available is of the order of 1500 km. A gravity gradiometer will offer the potential to improve resolution over the entire Earth to a few hundred kilometers.		
		3000 (6600)	4.6/4 (15/13.3)	90°/200 (108) Circular

TABLE X-2. (Continued)

PAYLOAD CODE	PAYLOAD	PAYLOAD OBJECTIVES AND DESCRIPTIONS		
		WEIGHT kg (lb)	DIMENSIONS (Length/Diameter) m (ft)	DESTINATION (Incl./Apo./Per.) km (n.mi.)
EOP-6	Mini-LAGEOS	Will provide a series of dense satellites at varying Earth orbits equipped with laser retroreflectors to measure with broad coverage plate motions, regional motions, polar motions, and rotational variations and to better determine the Earth's gravity field.		
		100 (220)	0.5/0.5 (1.6/1.6)	28.5°, 55°, 90°/650 (350) Circular
EOP-7	GRAVSAT	Will map the Earth's gravity field in sufficient detail to reflect the structure of the Earth's crust as it applies to the understanding of plate tectonics (which is fundamental to earthquake mechanisms), and the formation of mineral resources.		
		2400 (5300)	2.7/2 (8.9/6.6)	90°/200 (108) Circular
EOP-8	Vector Magnetometer Satellite	Will obtain high-resolution global data on the fine structure and variations of the magnetic field for use in (a) studies of crustal motion and subcrustal processes, and (b) an identification of mineral deposits.		
		150 (330)	1.3/1.4 (4.3/4.6)	90°/400 (216) Circular
EOP-9	Magnetic Monitor Satellite	Will measure changes in the Earth's magnetic field stemming from extra-terrestrial influences, so as to provide current reference fields in support of the low-altitude Vector Magnetometer Satellite measurements of localized		

TABLE X-2. (Concluded)

PAYLOAD CODE	PAYLOAD	PAYLOAD OBJECTIVES AND DESCRIPTIONS		
		WEIGHT kg (lb)	DIMENSIONS (Length/Diameter) m (ft)	DESTINATION (Incl./Apo./Per.) km (n.mi.)
	Magnetic Monitor Satellite (Concluded)	magnetic field changes associated with crustal motions and subcrustal phenomena.		
		200 (440)	1.3/1.4 (4.3/4.6)	28°/2000 x 1000 (1080 x 540)
	Sortie Payloads			
EOP-10	(Earth and Ocean Dynamics Experiments)	Will perform experiments related to better determination of Earth and ocean dynamics using such instruments as radar altimeter, microwave scatterometer, laser profilometer, precise multi-imaging radar, and FM correlation radar. Will conduct measurements of geomagnetic field using magnetometers. Will use the Shuttle pallet in the Sortie mode to develop and validate new spaceborne sensors and instrumentation for Earth dynamics and ocean dynamics measurements.		
		Note: Earth Observations, Earth and Ocean Physics, and Communications and Navigation Sortie payloads flown together.		
		11 300-12 200 (25 000-27 000) (Includes Expendables)	18.3/4.3 (60/14)	60°/Low Earth Orbit

TABLE X-3. COMMUNICATIONS AND NAVIGATION PROGRAM

Payload Code	Payload	CY	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	Total
	Automated Spacecraft																					
C/N-1	Applic. Tech. Sat.			1																		1
C/N-2	Coop. Applic. Sat.				1																	1
	Total			1	1							0		0	0	0	0	0				2
	Sortie Payloads																					
CN/3	(Antenna Configurations Laser Technology, Traffic Management Techniques, Energy Transfer Experiment)										1	1	1	1	1	1	1	1	1	1	1	11

Note: ○ Approved and Ongoing

TABLE X-3. (Concluded)

PAYLOAD CODE	PAYLOAD	PAYLOAD OBJECTIVES AND DESCRIPTIONS		
		WEIGHT kg (lb)	DIMENSIONS (Length/Diameter) m (ft)	DESTINATION (Incl./Apo./Per.) km (n. mi.)
	Automated Spacecraft			
C/N-1	Applications Technology Satellite	Will provide an oriented, stable spacecraft platform at synchronous altitude for advanced technology experiments in the categories of communications, meteorology, spacecraft technology and science. Will contribute to antenna technology and study interferometry, precision station-keeping, and millimeter wave communications techniques.		
		1360 (3000)	7.5/3 (25/9)	0°/Synchronous Orbit
C/N-2	Cooperative Applications Satellite	Will advance technologies for future space-based communications systems involving test of high power, 12 GHz superefficient power tubes, and deployable solar power arrays.		
		346 (760)	2.1 (7)/2.1 (7)	0°/Synchronous Orbit
	Sortie Payloads			
C/N-3	Com/Nav Sortie (Antenna Configurations Laser Technology, Traffic Management Techniques)	Will conduct experiments to advance the technology associated with high performance antennas, high power vacuum tubes, precision attitude determination, and laser communications. Note: Earth Observations, Earth and Ocean Physics, and Communications and Navigation Sortie payloads flown together.		
		11 300-12 200 (25 000-27 000) (Includes Expendables)	18.3/4.3 (60/14)	60°/Low Earth Orbit

TABLE X-4. SPACE PROCESSING PROGRAM

Payload Code	Payload	CY 73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	Total
	Sortie Payloads																				
SP-1	(Crystal Growth, Biological Separation, Metallurgy)								1	2	4	4	4	4	4	4	4	4	4	4	43

TABLE X-4. (Concluded)

PAYLOAD CODE	PAYLOAD	PAYLOAD OBJECTIVES AND DESCRIPTIONS		
		WEIGHT kg (lb)	DIMENSIONS (Length/Diameter) m (ft)	DESTINATION (Incl./Apo./Per.) km (n.mi.)
	Sortie Payloads			
SP-1	Space processing modules for work in: Metallurgy Crystal Growth Electronic Materials Biological Applications Ceramics and Glass Chemical Processes Physical Processes in Fluids	Will provide capabilities that can be matched to the resources of most Shuttle missions for R& D on materials science and technology in a weightless environment. Payloads will be made up from components provided in a large inventory of general purpose experimental apparatus, including control and instrumentation equipment, furnace heat treating apparatus, levitation heat treating systems, biological processing equipment, and diverse general purpose apparatus for experiments falling outside the above principal divisions. Equipment in the inventory will be modified to meet the needs of experimental investigators as they evolve, and updated to incorporate advances in technology during the life of the program.		
		2300–11 800) (5000–26 000) (Includes Expendables)	1.5–18.3/4.3 (5–60/14)	28.5°/Low Earth Orbit

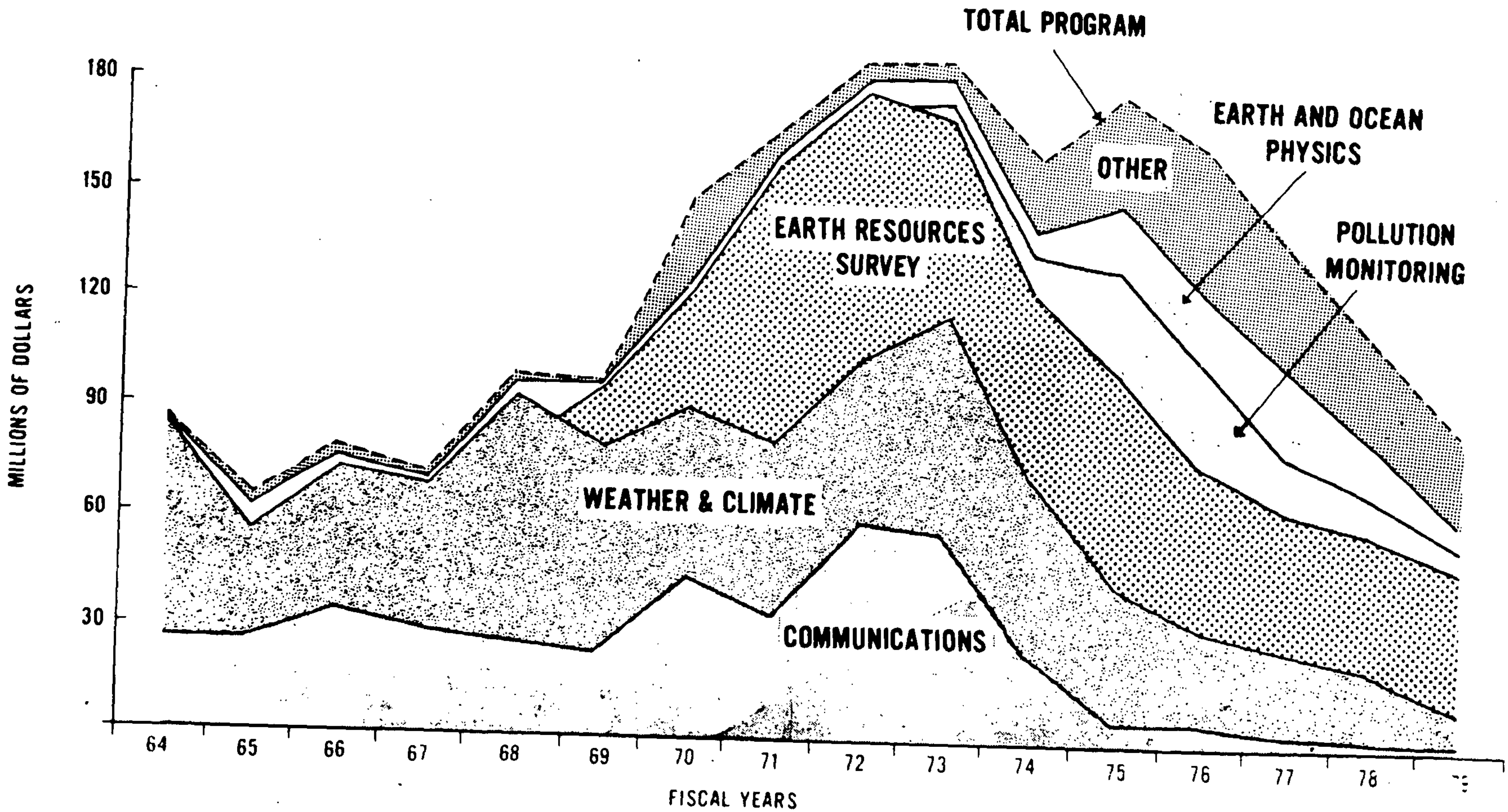

Figure X-1. Office of Applications — funding history and future plans, approved program.

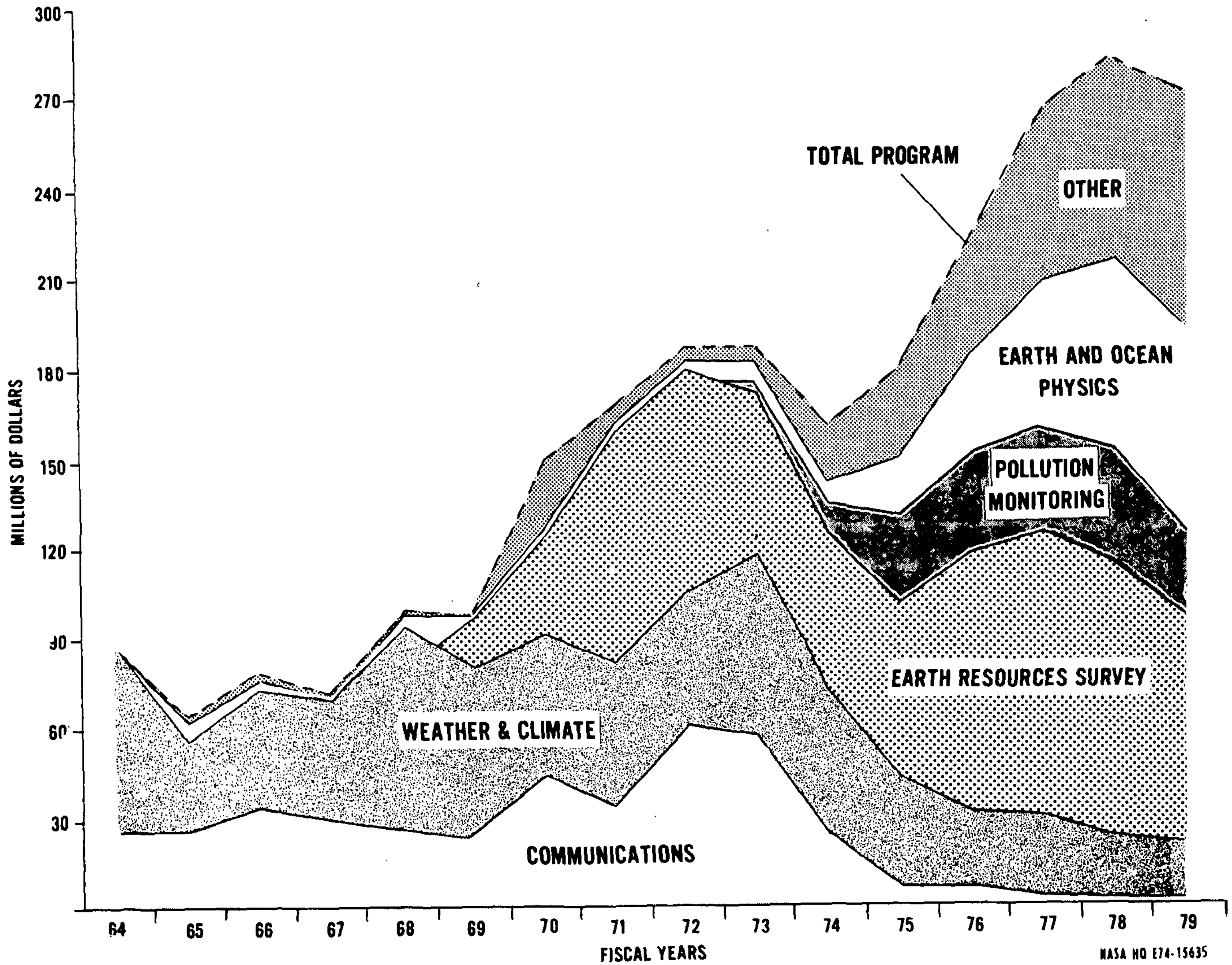

Figure X-2. Office of Applications — funding history and future plans, approved program and FY-76 — FY-79 new starts.

CHAPTER XI. KEY REFERENCES

CHAPTER XI. KEY REFERENCES

Each program area has included in its chapter a section listing references cited in the text. More extensive bibliographies have been transferred to the Appendices. A brief list of basic references, pertinent to the overall applications program, follows:

1. Survey of the Space Applications Program; For the Benefit of Mankind. NASA, Office of Technology Utilization, May 1967.

2. Useful Applications of Earth Oriented Satellites. Report of the Central Review Committee, National Academy of Sciences Summer Study on Space Applications, 1967, 68. January 1969 (Supported by Summaries of Panel Reports in 13 separate panel reports).

3. The Budget of the United States, Fiscal Year 1975. Available from the Superintendent of Documents, Washington, D. C., 4 volumes.

4. The Space Program in the Post-Apollo Period, A Report of the President's Science Advisory Committee. Prepared by the Joint Space Panels, Superintendent of Documents, Washington, D. C.

5. Space Task Group Report to the President, The Post-Apollo Space Program: Directions for the Future. September, 1969.

6. NASA 1975 Authorization Hearings; Hearings before Subcommittee on Space Science and Applications. U.S. House of Representatives, 93rd Congress, 2nd Session, February and March 1974, Part 3.

CHAPTER XII. ACRONYMS

CHAPTER XII. ACRONYMS

AAFE	Advanced Applications Flight Experiments
AASIR	Advanced Atmospheric Sounder and Imaging Radiometer
ADC	Attitude Determination and Control
AEC	Atomic Energy Commission
AIBS	American Institute of Biological Sciences
ALSEP	Apollo Lunar Surface Experiment Package
APIB	Applications Program Integration Board
APT	Automatic Picture Transmission
ARC	Ames Research Center
ARIES	Astronomical Radio Interferometric Earth Surveying (Experiment)
ASTP	Apollo-Soyuz Test Project
ASVT	Application System Verification Tests
ATS	Applications Technology Satellite
ATT	Advanced Transport Technology
AVHRR	Advanced Very High Resolution Radiometer
BUV	Backscatter Ultraviolet
BUV/TOMS	Backscatter Ultraviolet/Total Ozone Mapping Spectrometer
C&N	Communication and Navigation
CAS	Cooperative Applications Satellite
CDA	Command and Data Acquisition Station

CIAP	Climatic Impact Assessment Program
CIR	Coherent Imaging Radar
CMRN	Cooperative Meteorological Rocket Network
COMSAT	Communications Satellite Corporation
COPE	Carbon-Monoxide Pollution Experiment
CPRA	Compressed Pulsed Radar Altimeter
CTS	Communication Technology Satellite
CZCS	Coastal Zone Color Scanner
DCP	Data Collection Platforms
DCRS	Data Collection Relay Satellite
DCS	Data Collection System
DOC	Department of Commerce
DOD	Department of Defense
Domsat	Domestic Satellite
DOT	Department of Transportation
DSN	Deep Space Network
DST	Data Systems Test
EMI	Electromagnetic Interference
EOAP	Earth Observations Aircraft Program
EOLE	French Meteorological Satellite
EOPAP	Earth and Ocean Physics Applications Program
EOS	Earth Observatory Satellite

EOSMRG	EOS Mission Review Group
EPA	Environmental Protection Agency
ER	Earth Observations Programs Office
ERB	Earth Radiation Budget
EREP	Earth Resources Experiment Package
EROS	Earth Resources Observation System
ERPIB	Earth Resources Program Integration Board
ERS	Earth Resources Survey
ERSPRC	ERS Program Review Committee
ERTS	Earth Resources Technology Satellite
ESMR	Electrically Scanning Microwave Radiometer
ESRO	European Space Research Organization
ESSA	Environmental Survey Satellite
EVA	Extravehicular Activity
EXAMETNET	Experimental Inter-American Meteorological Rocket Network
FAA	Federal Aviation Administration
FCC	Federal Communications Commission
FGGE	First GARP Global Experiment
GARP	Global Atmospheric Research Program
GATE	GARP Atlantic Tropical Experiment
GEOS	Geodynamic Experimental Ocean Satellite; also, Geodetic Satellite

GLU	Global Land Use
GOES	Geostationary Operational Environmental Satellite
GOS	Global Observing System
GSFC	Goddard Space Flight Center
GVHRR	Geosynchronous Very High Resolution Radiometer
HCMM	Heat Capacity Mapping Mission
HCMR	Heat Capacity Mapping Radiometer
HET	Health/Education Telecommunications
HIRS	High Resolution Infrared Sounder
HRPI	High Resolution Pointable Imager
HRSCMR	High Resolution Surface Composition Mapping Radiometer
HSI	High Speed Interferometer
HUD	(Department of) Housing and Urban Development
ICCERSP	Interagency Coordination Committee for the Earth Resources Survey Program
IDOE	International Decade of Ocean Exploration
IFOV	Instantaneous Field of View
INTELSAT	International Telecommunications Satellite
IR	Infrared
IRIS	Infrared Interferometer Spectrometer
IRLS	Interrogation Recording Location System
IRR	Infrared Radiometer
ISAGEX	International Satellite Geodesy Experiment

ITCZ	Intertropical Convergence Zone
ITOS	Improved TOS
ITPR	Infrared Temperature Profile Radiometer
ITU-WARC	International Telecommunications Union/World Administrative Radio Conference
IUS	Interim Upper Stage
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
JURG	Joint Users Requirements Group
KSC	Kennedy Space Center
LACATE	Lower Atmosphere Composition and Temperature Experiment
LAGEOS	Laser Geodynamic Satellite
LaRC	Langley Research Center
LeRC	Lewis Research Center
LEST	Large Earth Survey Telescope
LNG	Liquid Natural Gas
LRIR	Limb Radiance Inversion Radiometer
LTA	Lighter-than-air (vehicles)
MAPS	Measurement of Air Pollution from Satellites
MHD	Magnetohydrodynamics
MIUS	Modular Integrated Utility System (HUD program)
MOMS	Multi-megabit Operation Multiplexer System

MOU	Memorandum of Understanding
MS/MS	Materials Science and Manufacturing in Space
MSFC	Marshall Space Flight Center
MSFEB	Manned Space Flight Experiments Board
MSPRB	Meteorological Satellite Program Review Board
MSS	Multispectral Scanner
MUSE	Monitor of Ultraviolet Solar Energy
MWS	Microwave Wind Scatterometer
NAS	National Academy of Sciences
NASA	National Aeronautics and Space Administration
NBS	National Bureau of Standards
NCAR	National Center for Atmospheric Research
NDPF	NASA Data Processing Facility
NEMS	Nimbus-E Microwave Sounder
NERC	National Environmental Research Center
NGSP	National Geodetic Satellite Program
NIH	National Institute of Health
NOAA	National Oceanic and Atmospheric Administration
NOMSS	National Meteorological Satellite System
NPDF	NASA Data Processing Facility
NRL	Naval Research Laboratory
NSF	National Science Foundation

NTFF	Network Test and Training Facility
OA	Office of Applications (NASA)
OART	Office of Advanced Research and Technology (NASA)
OAST	Office of Aeronautics and Space Technology (formerly OART)
OCC	OPLE Command Center
OMB	Office of Management and Budget
OMSF	Office of Manned Space Flight
OPLE	Omega Postion Location Experiment
OSIP	Operational Satellite Improvement Program
OTP	Office of Telecommunications Policy
PDP	Project Development Plan
PLACE	Position Location and Communication Experiment
PMR	Pressure Modulated Radiometer
PPME	Pacific Plate Motion Experiment
PRC	Planning Research Corporation
R&D	Research and Development
R&RR	Range and Range Rate
R&T	Research and Technology
RADSCAT	Radiometer/Scatterometer
RBV	Return Beam Vidicon
RFP	Request for Proposal

RPM	Radiation Polarization Measurements
RTG	Radioisotope Thermoelectric Generator
SAFE	San Andreas Fault Experiment
SAGE	Stratospheric Aerosol and Gas Experiments
SAM-II	Stratospheric Aerosol Measurement
SAMS	Stratospheric and Mesospheric Sounder
SAMSO	Space and Missile Systems Office
SAR	Synthetic Aperture Radar
SATS	Small Applications Technology Satellite
SBUV/TOMS	Solar-Backscattered Ultraviolet/Total Ozone Mapper System
SCAMS	Scanning Microwave Sounder
SCEP	Study of Critical Environmental Problems
SEASAT	Sea State Satellite for Ocean Physics
SEOS	Synchronous Earth Observatory Satellite
SHF	Superhigh Frequency
SIRS	Satellite Infrared Spectrometer
SITE	Satellite Instructional Television Experiment
SMMR	Scanning Multichannel Microwave Radiometer
SMS	Synchronous Meteorological Satellite
SPM	Solar Proton Monitor
SPRB	Satellite Program Review Board

SR	Scanning Radiometer
SR&T, SRT	Supporting Research and Technology
SSPD	Shuttle System Payload Data
SST	Satellite-to-Satellite Tracking
SSTIR	Sea Surface Temperature Infrared Radiometer
STDN	Standard Tracking Data Navigation; also, Space Tracking and Data Network
STS	Space Transportation System
TCV	Terminal Configured Vehicle
TDRS	Tracking and Data Relay Satellite (system)
TDRSS	Tracking and Data Relay Satellite System
THIR	Temperature Humidity Infrared Radiometer
TOS	TIROS Operational Satellite
TOVS	Tiros Operational Vertical Sounder
TM	Thematic Mapper
TWERLE	Tropical Wind, Energy Conversion, and Reference Level Experiments
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture
USDC	U.S. Department of Commerce
USDI	U.S. Department of Interior
USGS	U.S. Geological Survey
USRA	Universities Space Research Association

UT-1	Universal Time
VAB	Vehicle Assembly Building
VAS	VISSR Atmospheric Sounder
VHF	Very High Frequency
VHRR	Very High Resolution Radiometer
VIMS	Virginia Institute of Marine Science
VISSR	Visible Infrared Spin-Scan Radiometer
VLBI	Very Long Baseline Interferometer
VTPR	Vertical Temperature Profile Radiometer
WWW	World Weather Watch